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ABSTRACT

This volume's 301 papers are organized by 16 special interest groups, including: service delivery practice, personal transportation, augmentative and alternative communication, prosthetics and orthotics, quantitative assessment, service delivery policy, technology transfer, sensory aids, wheeled mobility and seating, electrical stimulation, computer applications, rural rehabilitation, robotics, biomechanics, information networking, and gerontology. (JDD)

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RESNA '87

MEETING THE CHALLENGE

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June 19-23, 1987

San Jose, California

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RESNA '87

Meeting the Challenge

Proceedings of the 10th Annual Conference on Rehabilitation Technology

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Foreword

These proceedings of the 10th Annual Conference on Rehabilitation Technology represent a benchmark in professional efforts to bring engineering and technology to bear on the needs of disabled individuals.

Although this is called the 10th Annual Conference, at least 5 yearly conferences preceded this series which addressed "systems and devices for the disabled." As this proceedings demonstrates, our knowledge and our ability to implement rehabilitation engineering and technology have grown. Today's rehabilitation engineering and technology has now become a unique body of knowledge that is applied in the process of rehabilitation.

This year, RESNA celebrates its 8th anniversary, and it is interesting to note how the organization has developed during those 8 years. The RESNA of 1987 is a mature organization, ready to aggressively pursue immediate and future opportunities.

This proceedings represents the single largest compilation of papers ever accumulated on the subject of rehabilitation engineering and technology. We all share in congratulating the 590 authors who have submitted 301 papers; the SIGs for their organization of materials; and members of the conference committee who developed and implemented this 10th Annual Conference. Finally, congratulations to everyone who is stepping up to meet the challenge!

C. Gerald Warren, M.P.A.
President

Larry Leifer, Ph.D.
Conference Cochair

John Brabyn, Ph.D.
Conference Cochair

June 1987

Preface

Welcome to RESNA 87! And welcome to California for the second time, RESNA! We here in Northern California are pleased to greet you to this land of snow-capped mountains, rushing streams, green vineyards, fine wines, cultural excitement, artistic excellence, educational ferment, and technological innovation. What better place to attend a major conference, celebrate a decade's worth of organizational contributions, rekindle old friendships, make new acquaintances, visit industrial and research centers, hear from leading experts in myriad fields, and participate in the shaping of one's discipline through the discussions—both formal and informal—that accompany sessions, meals, and the numerous social events.

We're doing RESNA differently this year! In particular, we are:

- accommodating an unprecedentedly high number of presenters and presentations;
- using posters to present ongoing scientific and clinical work;
- offering thematic Symposia to probe important current issues;
- introducing an All-SIG Symposium headed by the Conference Cochairs, to discuss overarching scientific issues;
- changing the *Proceedings* to incorporate:
  - a more compact page size;
  - a topical organization, to reflect the Conference structure; and
  - separate Symposium *Introductory* pages, providing overviews by Symposium organizers and SIG Chairs.

We look forward to your participation! Much will be happening at RESNA 87, in both familiar activities and new ones, and we invite you to join in them all. Come, learn, participate, socialize, and enjoy!

Happy 10th Birthday, RESNA Annual Conference!

Richard D. Steele
William A. Gerrey
Scientific Sessions Cochairs

June 1987

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Table of Contents

Page

Special Interest Group 1: Service Delivery Practice

Service delivery practice SIG. 2
Current trends in rehab engineering education — university training program 3
Staff development in rehabilitation technology services. 5
Billing practices and strategies for obtaining funding for rehabilitation engineering technology services - presentation summary. 8
Service delivery marketing and operating in the private sector 9
Measuring the benefits of technology in the rehab setting. 10
Measurement of efficacy of technology: a participatory process. 11
Rehabilitation technology services: a mobile rehabilitation engineering department. 13
Establishment of a competitive industry to employ disabled persons: layout of facilities 15
A powered air purification device for personal, portable use by persons with severe respiratory allergies. 18
Considering societal costs in judging the performance of predictive models of low back pain disability. 21
Initiation of adaptive equipment service at the Cleveland Clinic Foundation. 24
Research vs service delivery: you can have your cake and eat it too 26
A trans-disciplinary training model for rehabilitation technology specialists. 29
Effects of orientation to the body and input device on task performance. 32
The technical aids and assistance for disabled center: a consumer project 35
Service delivery in a dependency reduction program 37
Powered height adjustment for a lectern and filing cabinet to be used by an employee in a wheelchair 40
RIT: a model for technological applications 43
A structural and functional analysis of rehabilitation delivery systems. 46
Implementing a service delivery program: experiences in Pennsylvania. 49
Arguments for rehabilitation engineering services. 52

Special Interest Group 2: Personal Transportation

Improving reliability of personal transportation systems 56
The carchair story 57
Transfer of current technology to adaptive devices and its impact on the driving public both able bodied and physically challenged 60
Performance standards for adaptive equipment in personally licensed vehicles used by persons with disabilities. 62
Driver assessment, education and training for the disabled 65
An assistive mobility device for independent living. 68
A mobile assessment laboratory for evaluating the driving skills of disabled individuals 71
Psychometric predictors of driving ability among able-bodied and disabled individuals. 74
Computer programs for cognitive rehabilitation: usefulness in predicting driving skills among disabled & nondisabled persons. 77
Wally's trolley. 79
A small-scale vehicle for assessing and training driving skills among the disabled 81
Development of a compact lift and transfer device. 84
Driving task evaluation and training vehicle for the disabled: small-scale vehicle. 87

Special Interest Group 3: Augmentative and Alternative Communication

Collaboration - an essential issue in the development of augmentative communication devices 91
Designing a computerized visual communication system for severe aphasics 94
Voice output communication aids: a survey and an evaluation 97
Preliminary validation of prescription guide for selection of communication aids 100
Speech recognition of impaired speech. 103
A comparison of palantype and stenograph keyboards in high- speech output systems. 106
Development of a real-time expert system for automatic adaptation of scanning rates. 109
A line of gaze communication system. 112
Lexical prediction techniques applied to reduce motor requirements for augmentative communication. 115
Semantic compaction for sub-sentence vocabulary units compared to other encoding and prediction systems 118
Exploiting word frequencies and their sequential dependencies. 121
The use of syntax in a predictive communication aid for the physically handicapped 124
A communication aid which models conversational patterns 127
Predictive programs: writing tools for severely physically disabled students. 130
Linguistic efficient communication systems; consideration of feedback principles 133
Designing enhancements for and providing technical feedback to manufacturers of augmentative communication equipment 136

Clinical application of an auditory scanning software program with severely disabled, nonspeaking individuals. 139
Computer aided assessment for the selection of augmentative communication system characteristics. 142
A rugged vane-type breath actuated call switch 145
Expert systems applied to rehabilitation engineering: a new approach to the evaluation of control. 148
Quantification of relative importance of communication needs 151
Application software: a new concept in augmentative and alternative communication 154
Patterns of learning in aphasics trained on a computer-based visual communication system 157
A strategy and tools to train augmentative communication skills with single switch users 160
Representations of "verbs" in a computerized visual communication system 162
RPM for accessing large vocabulary files 165
"Yo voy, el va": a case study in integrating Spanish, symbols and a synthetic speech output device. 168
Computer based communication systems - the future. 171
Cognitive abilities implicated in the use of communication aids. 174
Multi-character key text entry using computer disambiguation 177
Quantification of device evaluation. 180
Computer aided construction of nonverbal communication boards. 183

Special Interest Group 4: Prosthetics and Orthotics

Ways to control multifunction myoelectric prostheses 187
Five new amplifiers for detecting myo- and bioelectric signals 190
Quantitative assessment of the importance of elbow prosthesis dynamic behavior in the performance of manual tasks. 193
Making the case for body-powered upper-limb prostheses 196
New design for a body-powered prosthetic prehensor 199
The research on a total arm electrical powered prosthesis -- motion program. 202
Do we need a prosthetic prehensor which is neither hook nor hand?. 204
An adaptive handle for a safety razor. 207
Reacher which provides low joint forces. 210
Development of a protective helmet for disabled people 213
A design for the back of seated positioning orthoses that controls pelvic positioning and increases head control. 216
Extending an idea: an arm and leg exerciser for young physically disabled children. 219
Crutches: low tech or high interest?. 222
Assessment of light weight twister torsion cable braces and canes on one youngster 225
Resting splint for acute neurologically damaged patients with hypertonic gastroc-soleum muscle groups. 227
The custom cuirass ventilator - an alternative for the respirator dependent client 229
An ultrasonic bladder sensor for persons with incontinence 232
Micro-enema dispenser for quadriplegics. 235

Special Interest Group 5: Quantitative Assessment

Quantitative testing technology: overview/marketing issues. 239
The available motions inventory: evaluation tool for the productive employment of handicapped individuals. 240
Quantification of muscle strength, muscle endurance and range of motion. 243
Quantitative functional assessment in a university rehabilitation engineering center 246
Design and development of a metabolic interface to collect selected measures on children with cerebral palsy 249
An apparatus for measuring knee joint motion "in vivo" 252
Manual goniometer system for optimizing medio-lateral hip position in adaptive seating 254
An in vivo evaluation of four types of total knee arthroplasties 256
Initial experience with the data glove, a semi-automated system for quantification of hand function 259
The available motions inventory: an assessment instrument for pre-vocational individuals. 261
Effect of different seating orientations on upper extremity function in children with spastic and athetoid cerebral palsy 264
A magneto-mechanical 3-D surface contouring system 267
Analysis of compression, shear and surface tension on seat cushions. 269
Differences between backrest/seat surface angle and anatomical hip flexion angle in adaptive seating 272
Device for quantitative position and motion analysis 275
An in vitro comparative study of total knee arthroplasty 278
Data collection on gait and energy expenditure of above knee amputees. 281
Quantitative functional assessment of control systems for upper-extremity prostheses 284
A new tool for stroke rehabilitation study 287
Technology for clinicians: measurement of functional communication of persons with aphasia. 290
Application of a device for the quantitative testing of muscle strength. 293
Low back pain disability: comparing physicians' predictions to expert and empirical models. 296
Determination of body segment inertial properties. 299
Skin response to pressure loading by the bent finger technique 302
Digital interface pressure evaluator 305

Experimental research designs for the scientist-practitioner 308
Effect of unilateral arm restraint on upper extremity function in cerebral palsy 311
The design and use of microcomputerized real-time muscle fatigue monitor based on the median frequency shift in the electromyographic signal 314
A device and protocol to objectively measure cervical motion 317
Comparative analysis of forward and backward human walking and stepping 320
Comparative evaluation of pressure distribution on flat foams and contoured cushions 323
Computer-aided back analysis system 326
Electric goniometer designed for measuring hip flexion angle in children with cerebral palsy in the seating position 329
Development of a wheelchair aerobic fitness trainer 331
Technology for clinicians: mobile microcomputer for training pressure sore preventive behavior 333
The effect of length on the axial force applied to walking canes 336
Three dimensional shoulder joint measurement 338
Using the Occupational Therapy Comprehensive Functional Assessment (OTCFA) to evaluate the efficacy of technological intervention in rehabilitation 341

Special Interest Group 6: Service Delivery Policy

Approaching technological support as a lifelong need: why rehabilitation technology services need to be sustained in the community 345
A guidebook for establishing & operating a Rehabilitation Engineering Technology (RET) service-chapter 3 summary: program development & operation 348
Delivery of rehabilitation technology services in Australia 350
The Daniel M. Carney Rehabilitation Center - a unique service delivery system for persons with disabilities 353
The physician's role in obtaining rehabilitation technology 356

Special Interest Group 7: Technology Transfer

Linking Individuals to evaluation of rehabilitation issues 359
A portable suction device for tracheotomy tube 362
National survey of rehabilitation technology utilization in state vocational rehabilitation agenices 365
Beyond VELCRO^{tm}: a student project in human factors and design for people with special needs 368
Bending stiffness of backboards for acute spinal injury patient transport 371
Composite materials for rehabilitation devices 374
Design and implementation of an evaluation program for assistive devices used by people with arthritis 377
Increased independence through more accessible security 380
Performance assessment of environmental control units as used by high level spinal cord injured persons 383
Cost efficient technology for rehabilitation-- three examples 385

Special Interest Group 8: Sensory Aids

Sensory aids SIG 388
Digital hearing aids 389
A wearable digital hearing aid 392
Multimicrophone monaural hearing aids 395
Ambulatory testing of digi[illegible]earing aid algorithms 398
Speech perception with an eight-channel compression hearing aid and conventional aids in a background of speech-band noise 401
Experiments with a two-channel compression-limiting amplification system designed for profoundly deaf subjects 404
Discriminability of frequency-response irregularities in hearing aids 407
Orthogonal polynomial compression amplification for the hearing impaired 410
Evaluation of noise reduction techniques for hearing aids 413
Functional gain measurements of amplitude and phase 416
Human factors considerations in the design of large print displays for persons with visual impairments 419
Time and time again, say it without feeling: two new devices for deaf-blind people 422
Portapitch II: a multichannel tactile display of voice fundamental frequency 425
Development of speech perception skills in cochlear implantees 428
Development of a portable text communication environment for the visually impaired community 431
Automatic feature extraction for the transmission of american sign language over telephone lines 434
A computerized optacon tutor 437
Deaf persons deserve better than a TTY for communication 440
Experienced technology user survey: design/operational features for blind reading aid 443
Use of pressure zone microphones with FM auditory training equipment to improve signal to noise ratio 446
A blind student in a regular classroom using a computerized pen-and-paper substitute 448

A survey of potential users: design/operational features for a reading aid
for the visually impaired population. 451
Electronic braille note takers for the blind 454
A new combination unimanual and bimanual braille keyboard. 456
Audio and tactile feedback strategies for tracking 459
Work environment visual characteristics protocol: software for low vision rehabilitation. 462
Soldering with modern techniques and materials 464

Special Interest Group 9: Wheeled Mobility and Seating

Motor, perceptual, and cognitive factors that affect mobility control. 468
Evaluation of a test battery for assessment of electric wheelchair driving ability 471
Classification of wheelchair athletes. 474
Standing and its importance in spinal cord injury management 477
Anthropometric data for design of specialized seating and mobility devices a preliminary report. 480
Speed regulation in hand rim wheelchair propulsion 483
A spatial musculoskeletal model for wheelchair lever propulsion. 486
A custom wheelchair which allows for leg-assisted propulsion 489
Using a time delay to alleviate head oscillations with an electric wheelchair. 492
An energy-storage dc-dc converter for electric wheelchair drives 495
Improvements and performance of an adaptive battery monitor. 498
A new battery with very long life for electric wheelchairs 501
The application of fault tolerance to microprocessor-based wheelchair control systems. 504
Analysis of parameters related to the directional stability of rear caster wheelchairs 507
Trends in powered mobility for school aged physically handicapped children 510
Effect of seat surface stiffness on trunk muscle activity. 513
Body contours and pressure distributions of normal and sci subjects on wheelchair cushions 515
Effect of seating posture on pressure distribution 518
Effects of body position and center of gravity on tolerance of seated postures 521
A dynamic model of tissue deflection in a seated individual. 524
MPI seating system technical evolution 527
Effect of seat angle and lumbar support on seated buttock pressure 530
The comparison of support interface pressure measuring systems 533
An adaptable microcomputer based controller for electric wheelchairs 536
A universal wheelchair feedback controller 539
Microcomputer-based scanning interface for powered wheelchairs 541
Special wheelchairs for special people 544
Design and control of a curvilinear synchronous wheelchair 547
A comparison of three-wheeled human powered bicycles for persons with physical disabilities. 550
An adjustable height manual wheelchair for a vocational application. 553
Mobility systems for people of short stature: two case studies. 556
A variable position, compact folding wheelchair. 559
Customized wheelchair for a cerebral-palsied adolescent. 562
An independently adjustable attachment for a cable driven flexor hinge orthosis. 565
Clinical application of the adjustable "computer chair". 568
A head band system for anterior head support in a seating system 571
The meru rigid pelvic stabilizer for postural control. 573
Three dimensional machining of custom contoured polyethylene foam cushions 576
First national triathlon for the physically challenged 579

Special Interest Group 10: Electrical Stimulation

Restoring functional mobility to paraplegics 581
Neuroprostheses: past, present and future trends 582
Hemodynamic responses during electrically-induced leg and voluntary arm crank
exercise in lower-limb disabled males 583
Electromyographic study of the back step for development of electrical stimulation patterns. 588
Recruitment data for nerve cuff and epimysial electrodes 591
Command channels for upper limb neural prostheses. 594
Functional electrical stimulation of hip extension and abduction affected
by activity of the trunk. 597
Ischial blood flow of seated individuals during electrical muscle stimulation. 600
A man/machine interface for control of an upper extremity functional neuromuscular
stimulating system. 603
Design of a quickly-assembled, light-weight leg orthosis for FES assisted paraplegic mobility. 606
Therapeutic and functional stimulation of arm in spastic hemiparetic patients -
a feasibility study 609
Quadriceps muscle response to functional neuromuscular stimulation during isokinetic
exercise and walking. 612
Voluntary strength gains in paretic muscle after hybrid (FNS-voluntary) exercise training. 615
An electrical stimulator for functional neuromuscular stimulation exercise 618

Experience with ankle-foot orthoses and paraplegic subjects using functional neuromuscular stimulation . . . 621
A comparative study of the functionality of the second generation of peroneal stimulators . . . 624
Towards the manufacture of an ideal artificial nerve growth medium . . . 627
Tetanic endurance and twitch moment of electrically conditioned paralyzed muscle . . . 630
Using stretch sensors to measure knee and hip angles . . . 633
The effects of FNS on disuse osteoporosis . . . 635
Standing by functional neuromuscular stimulation in the laboratory and the home: case reports of 18 paraplegic individuals . . . 637
Efficiency of volitional versus electrically evoked knee extension exercise . . . 640
Epimysial electrical stimulation: short-term therapeutic applications . . . 643
Simulation of paraplegic postural control induced by functional neuromuscular stimulation . . . 646
Implementing trunk control in FNS walking systems . . . 649
Paraplegic subjects' experience in an FNS research program . . . 651
The feasibility of using strain measurements in an ankle-foot orthosis as a feedback signal for closed-loop FNS gait . . . 654
Results of FES application to 71 SCI patients . . . 657
Enhancement of ulcerated tissue healing by electrical stimulation . . . 660

Special Interest Group 11: Computer Applications

Preface to the symposium on applications of shape-recognition technology in rehabilitation engineering . . . 664
Problems of and requirements for character recognition systems . . . 666
Image processing and image understanding . . . 669
The future of seeing-eye robots in rehabilitation engineering . . . 672
The development of a microelectronic axon processor silicon chip neuroprosthesis . . . 675
Alternative access methods for the IBM family of personal computers and true compatibles . . . 678
Impact of standards on future environmental control systems . . . 680
The development of a heavy duty joystick . . . 683
Software for screen display of keyboard for no-hands typing via ultrasonically sensed head movements . . . 685
The development of a non-contact eyetracking system for communication and control . . . 688
A 'smart' microprocessor-based infra-red data link to enable wireless wheelchair-to-'landbase' communication with personal computer and environmental control devices . . . 691
CAD-clad computer-aided clothing design for people with special needs . . . 694
Evaluation of accessability by the physically disabled student to the icon computer . . . 697
The mod keyboard: a progress report . . . 699
Effect of assigning standard computer keyboard operating characteristics on quadriplegic input rate . . . 702
Low cost high tech: computer applications that work . . . 705
An interactive Cobol editing system: keystroke reduction application for disabled students . . . 708
Keyboard equivalent for mouse input . . . 711
Altkey: a special inputs program for the IBM-PC . . . 714
Comparison of three PC-XT based voice recognition systems . . . 717
A computer interface for the disabled based upon a code of vectors related to user motion . . . 720
A DC input mouse emulator . . . 723
Prototype development of a system providing for initial assessment of the dynamics/kinematics of bipedal motion . . . 726
Motigame . . . 729
Cost effective graphics for real time driving simulation . . . 731
Casper: computer assisted speech perception evaluation and training . . . 734
A progression from simple encoding to morse code . . . 737
Selecting adaptive input devices for personal computers . . . 740
A method for the dissemination of very inexpensive communication systems . . . 742
The implementation of a software methodology for communication aids . . . 745
The architecture of an executive workstation for the disabled . . . 748
Features to increase the accessibility of computers by persons with disabilities: report from the industry/government task force . . . 750

Special Interest Group 12: Rural Rehabilitation

International aspects of rural rehabilitation introductory symposia statement . . . 754
Agricultural-related disabilities in China/a perspective . . . 756
Putting the tools in the hands that can use them: wheelchairs in the third world . . . 759
Rural rehabilitation: on the road again . . . 762
Breaking new ground's Mark II chairlift for agricultural equipment . . . 765
Agricultural worksite assessment . . . 767

Special Interest Group 13: Robotics

The use of robotic manipulators as cognitive and physical prosthetic robotic aid . . . 770
Experimental study of a natural-language interface to an instructable aid for the severely disabled . . . 773
Evaluation of a table top robotic aid for quadriplegics . . . 776
Robotics at Tufts-New England Medical Center: a progress report . . . 778
Development of the manus wheelchair-borne manipulator: a progress report . . . 781
Development of a robotic feeding device for disabled individuals . . . 784
Object localization using multi-resolution sensing . . . 787
Automated robotic grasping by use of optical proximity sensors . . . 790
Navigational algorithms for a mobile robotic aid for the severely disabled . . . 793
Design of a second generation desk-top robotic aid . . . 796
Task analysis for the use of robotic manipulators . . . 799
CALVIN: new perspectives on a robot language . . . 802
Workplaces for the handicapped in flexible production automation with robots . . . 805

Special Interest Group 14: Biomechanics

Hip dynamics in stair climbing and rising from a chair following hip arthroplasty . . . 809
The added torque imposed on the lumbar spine during whole body vibration estimated using trunk muscle electromyography . . . 811
Finite element analysis as a method of pressure prediction at the below-knee socket interface . . . 814
Generation of surface anatomy from CT and MRI images . . . 817
The effect of foot wedging on knee and ankle mechanics . . . 820
The importance of physical activity to the maintenance of bone density . . . 821
Investigation of in vivo loading rate characteristics in a human hip joint . . . 823
Methods to reduce stress shielding in plated bones . . . 826
Differential diagnosis of pathological tremors according to mechanical load response . . . 829
Biomechanical modeling of the chiari hip osteotomy . . . 832
Evaluation of posture and balance in cerebral palsied children . . . 835
Epiphyseal replacement prosthesis . . . 838
The development and testing of an isokinetic strength testing device . . . 840
The effects of patellar size and patellar ligament length on knee joint mechanics - implications for rehabilitation . . . 843

Special Interest Group 15: Information Networking

The structure of information service delivery . . . 847
Sensory technology information service . . . 848
Information service delivery for physically disabled people . . . 850
Linkage: a conceptual view of information delivery in the rehabilitation field . . . 853
Starting an information service: issues and questions . . . 856
Trends influencing rehabilitation information development and delivery . . . 858
The center for special education technology . . . 861
Using voice mail technology to aid the disabled (aidline) . . . 864
Designing a database: theoretical considerations . . . 867
Assistive device information services in Michigan . . . 870
Clothing for special needs: an information arena . . . 873

Special Interest Group 16: Gerontology

Progress in preventive techniques for the elderly . . . 876
Wandering behavior of elderly nursing home residents: evaluation and intervention . . . 877
Guide to gerontology information and funding resources . . . 880
Trial of foam seat cushions used for the prevention of decubitis ulcers in the elderly . . . 883
A study of falls by the elderly . . . 885
Rehabilitation technology and design for the elderly: a gerontologist's perspective . . . 888

Special Interest Group 1

Service Delivery Practice

Chair: Mark N. Ozer, M.D.

SERVICE DELIVERY PRACTICE SIG

Mark N. Ozer
Jim Tobias
Gerald Weisman

At its inception, the Service Delivery Practice SIG resolved to develop a forum in which to share clinical applications of rehabilitation technology. The creation of such a forum was felt to be imperative for professional development.

This symposium arranged for the San Jose meeting by Kenneth Kozole and Glenn Hedman marks the implementation of some of the priorities in information exchange developed out of previous planning both at Memphis and Minneapolis meetings. Some of the topics to be discussed include those identified earlier:

1. Training of clinical staff
2. Linkage of training to clinical staff
3. Methods of needs assessment
4. Development of service delivery evaluation.

Other aspects of priority for this SIG include the development of new formats for presentation of data more appropriate for the character of service programs. Emphasis is on exemplary service programs with focus on case reports which demonstrate impact. The new format for paper presentations is as follows:

1. Innovative Technical Project papers will focus on interesting new applications of technology.

2. Illustrative Practices papers will focus on non-technical as well as technical reasons for a project's success or failure. The purpose of these papers is to explore other aspects of rehab. technology such as funding approaches, training, client-assisted design, unusual referral sources and so forth.

The format for these presentations should seek to use the following outline:

Problem definition:	A Description of the problem, including history of the client, environmental as well as social factors contributing to the problem as well as technical.
Problem solution:	How was the solution arrived at? How was the solution implemented? What were the technical aspects of the solution?
Costs:	What were the actual costs? What was the fee charged? Where did the money come from?
Results/Benefits:	How well did the solution solve the problem? How were the results measured? To what degree was the client involved in determining either the effects sought or the measurement of the actual results accomplished?

A major goal of the Service Delivery Practice SIG has been to provide an opportunity for the sharing of information between practitioners. The presentations at the annual meeting and the one-to-one contact provide an opportunity for sharing not only technical but also the non-technical aspects of service delivery. The "Yellow Pages" to be distributed this year provide another opportunity for networking to go on between practitioners throughout the year.

CURRENT TRENDS IN REHAB ENGINEERING EDUCATION -- UNIVERSITY TRAINING PROGRAM

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ABSTRACT

The University of Virginia has established a 2 year training program for students interested in the field of Rehabilitation Engineering. The focus of this program is on clinical experience as well as academic studies.

INTRODUCTION

The goal of the rehabilitation engineering program is to academically as well as clinically train students to become rehabilitation engineers. Clinical practice is a major component of the 2 year curriculum, and students spend approximately 15-20 hours per week seeing patients and working on clinically related projects. The coursework is designed to supplement this clinical experience, and to provide the students with the practical fundamentals they need to practiceas rehab engineers.

COURSEWORK

Each semester the students take a rehab engineering course, two biomedical engineering courses, and the clinical apprenticeship. The following is a typical curriculum:

Fall #1:	Rehabilitation Engineering I Physiology Medical Computers Clinical Apprenticeship
Spring 1:	Rehabilitation Engineering II Physiology Elective Clinical Apprenticeship
Summer:	Clinical Apprenticeship
Fall #2:	Rehabilitation Engineering III Medical Instrumentation Biomathematics Clinical Apprenticeship
Spring 2:	Rehabilitation Engineering IV Masters Project Elective Clinical Apprenticeship

Electives may be in any of the graduate engineering departments.

Rehabilitation Engineering I is the first of four courses. The focus of study is on disabilities, including medical, functional and psychosocial aspects of disability. The course is divided into four major blocks of study, including:

1) spinal cord injury and anatomy
2) amputations and rheumatic diseases
3) neurological and neuromuscular disease
4) genetic disabilities

Coursework coordinates closely with clinical practice, and medical professional in the medical community lecture to provide insight into the interactions between engineers and the medical staff concerned with rehabilitation.

Rehabilitation Engineering II focuses on areas of rehabilitation that the engineer is likely to become involved in, and some of the techniques used in each of these areas. Subjects covered include basic biomechanics, gait analysis, seating, mobility, communication, design, and ergonomics. Each student also completes an electronics project during the semester.

Rehabilitation Engineering III is a design course, focusing on practical design skill to help the student strengthen his/her skills to design for disabled persons. Coursework includes drafting, and in-depth review of select shop skills, a review of material science as well as coverage of practical material knowledge, a review of fundamental design concepts, human factor engineering, and design development sessions to guide the students in completing a masters project.

Rehabilitation Engineering IV focuses on the administrative/business skills often needed in the field of rehabilitation engineering. The course is structured as an analysis of a rehabilitation facility in terms of starting a new service delivery system. Throughout the project students address financial management issues, funds, department organization, physical facility needs, ploicy and procedures, co-worker and community training and education, and some extra items such as grant proposal writing and contract bidding.

CLINICAL APPRENTICESHIP

The clinical apprenticeship is designed to provide students with hands-on experience similar to what they would be responsible for in the field. A large majority of the work is in the area of special seating systems, but there are also projects in communication, home modifications, work-site evaluations, mobility devices, and ADL. By the second year, students are often completely responsible for client evaluation, problem solution and implementation, fabrication, and documentation.

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STAFF DEVELOPMENT
IN REHABILITATION TECHNOLOGY SERVICES

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INTRODUCTION

This paper addresses the professional background and development of individuals working in services of rehabilitation technology at Gillette Children's Hospital. Since the on-the-job training at Gillette is largely experiential, the working environment has a significant impact on the professional development of staff. For this reason, this paper also provides a brief overview of these services, their evolution, and organizational structure.

ORGANIZATIONAL STRUCTURE

Twenty-eight technical persons currently work in the Habilitation Technology Labs(HTL) of Gillette Children's Hospital. There are six sub-departments within HTL, as follows: Adaptive Equipment (5 persons), Rehabilitation Engineering (1), Sitting Support Orthotics and Upper Limb Orthotics(4),Prosthetics (3), Spinal Orthotics (4), and Lower Limb Orthotics (9). Other positions are in an administrative category, including the Director, Administrative Secretary, Receptionist and Orthotic Clinical Intern. Each of these sub-departments has a team leader, whose responsibilities include managing the work load, the personnel, and financial matters of that sub-department.

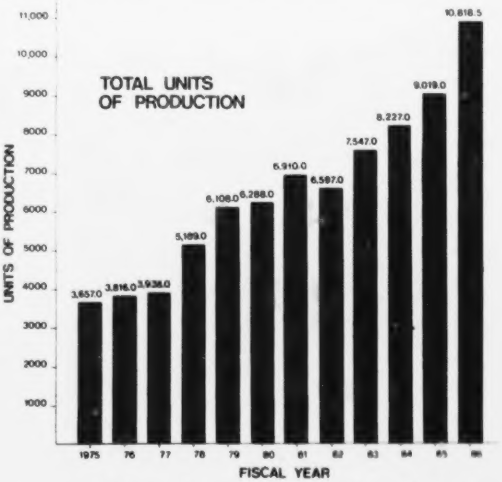
It is extremely important to note that the rehabilitation technology services are provided in a collegiate atmosphere where clients are evaluated by an interdisciplinary team involving some combination of these professionals: physician, orthotist, prosthetist, rehab. technologist, physical and occupational therapist, speech/language pathologist and psychologist. (Note: in this paper, the term "rehab. technologist" is used to define a technical person working in rehab. technology services who is not involved in the provision of typical orthotic or prosthetic services). Persons at all levels within the HTL, not just those with greater experience or team leadership roles, interact with physicians, therapists, and other professionals.

EVOLUTION OF SERVICES

Services began approximately 50 years ago with traditional orthotics and prosthetics. In addition to keeping pace with developments in orthotics and prosthetics, the last 13 years have included the addition of newer rehab. technology areas such as custom seating systems, mobility, and a wide variety of adaptive equipment. Evaluation programs have also been established in the areas of powered mobility, augmentative communication and environmental controls.

The typical client population served at Gillette has evolved to include adults as well as children. The most common disabilities among clients receiving services are cerebral palsy and myelomeningocele, but also served are clients with spinal cord injury, head injury, muscular dystrophy and other neuromuscular disorders.

We have a method for consistent year-to-year monitoring of work volume that is independent of inflation. The measurement units of this method are called Units of Production (UP's). To describe the HTL work volume increase from 1976 to 1986, we can compare 3,816 UP's in 1976 to 10,818.5 UP's in 1986. The following chart further describes this growth.



A major factor contributing to growth in the HTL service volume is a gradual increase in awareness of services, both within Gillette itself and throughout the community among clients, their families, community residential facilities, school clinicians and physicians. The addition of newer rehab. technology services has reflected the needs expressed by clients and their caretakers.

The gradual development of other rehab. technology services out of a traditional orthotics and prosthetics department, which has well established reimbursement and fabrication techniques, probably a primary factor in the current financial success and quality of these services.

TRAINING BACKGROUND

The diverse backgrounds of the specialists in rehabilitation technology within the HTL contribute significantly to the present cost effectiveness and quality of their services. Persons working in rehabilitation technology come from educational and working backgrounds in areas such as art or design, traditional orthotics and prosthetics, classical engineering, rehab. engineering internship, speech and language pathology, machinist work, electronics, communications and plastics technology.

When new persons are added to the HTL staff, we are not looking very closely for the new employees to have experience in rehabilitation technology, but are looking, instead, for potential. This potential is measured, as we are best able to read it, in their personality and intelligence. These traits, combined with the rich work experience at Gillette, have resulted in the high quality staff currently employed. We also feel that the diversity of backgrounds is valuable for maintaining vitality and for bringing creative solutions and experience from many fields. Within the HTL a balanced mix of persons with traditional orthotics and prosthetics and other backgrounds has worked well.

ON-THE-JOB EXPERIENCE

The on-the-job training of all HTL staff in rehab. technology services is largely experiential. The significant numbers of clients served at Gillette and their varying levels of disability facilitate this experiential training. A client follow-up system of at least annual clinic visits gives rehab. technology professionals an invaluable opportunity to evaluate their work over time. The instructive value of this follow-up system is enormous, since it allows staff to learn from their mistakes and make appropriate design and fabrication improvements.

Historically, Gillette has emphasized medical education. Within HTL, contact between the new employee and the client is initiated early in the employee's career. Newer employees are able to benefit from both the education and experience of those with more experience. Most training, however, is through supervised hands-on service to clients. In some cases, newer employees in training are matched up with more experienced employees who have exceptional skills.

Medical education is obtained informally by HTL staff as they interact and problem-solve with therapists, physicians and other clinicians at Gillette. It is one of the stated priorities of the HTL to listen to, and learn from, the families, caretakers, school team and other persons outside of Gillette who are working with each client. A significant amount of education is also obtained by the HTL staff from interaction with these families and professionals. Prior to any evaluation, information is obtained from these persons regarding the client's abilities and needs. The caretakers and school team are always included in the client evaluation and equipment design process. This provides an open forum for easy exchange of ideas and professional growth.

Individuals working in areas of rehab. technology at Gillette have had to increase their awareness of third party payers' requirements and create more effective billing procedures to assume a high rate of reimbursement for their services and equipment. Frequently, rationale for doing evaluations is provided to third party payors. Extensive documentation of a client's needs and justification must be submitted by the technical person(s) involved when equipment purchase is recommended. Although extremely time-consuming, this process does cause a person to carefully think through recommendations.

Considerable emphasis is put on making informal education available to the HTL employees through weekly educational inservicing, organized cooperatively by both the Gillette Habilitation Technology Labs and the PT/OT departments. Topics range from client case studies and product demonstrations, to client service philosophies and service delivery procedures. Subdepartments of the Habilitation Technology Labs also meet regularly to address business issues and to share new materials and design improvements. In addition, individuals are encouraged to attend work-related conferences and community seminars on professional and technical skills. Several individuals are choosing to obtain formal education in an Orthotic and/or Prosthetic Practitioner certification program offered locally.

The HTL at Gillette has a clearly designated allocation for staff educational support. The HTL, with a staff of 30, annual revenue of $1,746,038.00 and a total direct expenses budget of $1,078,526.00 in 1986,has an Education/Budget line item of $15,000.00.

SUMMARY: Advantages and Disadvantages

We feel the approach outlined in this paper has been effective but also has some shortcomings.

Advantages, in addition to those mentioned throughout this paper,include the non-transverse division of labor. This allows the HTL employees, from new technical persons with six months experience to team leaders with 10 or more years of experience, to all participate in the full range of service provision, including interviewing clients, device design, fabrication and fit. Another advantage is that learning in a real work situation and direct application of technology challenges people early in their careers and keeps them stimulated. In this environment people also develop a habit of designing and problem-solving quickly, which has a huge impact on the department's financial performance.

A form of staff development which relies heavily on experience, however rich,tends to fall short in areas which typically require more formal instruction such as anatomy, engineering theory and analysis. These strengths must be obtained by other means. The experiential training can sometimes leave "gaps" since it relies upon the mix of work coming through the department which may be incomplete. This phenomena depends upon the size of the facility and lessens as the department's size increases. A larger facility allows the rehab. technologist to see more each day and to benefit from the sharing of knowledge by more experienced professionals on how they have solved similar problems.

CLOSING

This paper attempts to present an overview of the professional development of individuals providing rehabilitation technology services at Gillette Children's Hospital. A special thanks is extended to Debbie Day, Karen Ostenso, Mark Payette and David Wilkie for their contribution to this paper. For any further information, we welcome inquiries to:

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BILLING PRACTICES AND STRATEGIES FOR OBTAINING FUNDING FOR REHABILITATION ENGINEERING TECHNOLOGY SERVICES - PRESENTATION SUMMARY

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BACKGROUND

This discussion will address some of the factors involved in securing financial support for RE Technology Services. The comments will be based on experiences gained in a University based outpatient program that has been in operation for over 12 years. Comments will reflect the results of having worked with third party payors located primarily in three states; Arkansas, Mississippi, and Tennessee.

TYPES OF SERVICES PROVIDED

By far the majority of services provided has been specialized seating for children and young adults. Seventy to eighty percent of the clients are severely disabled children, mainly with the diagnosis of of cerebral palsy or brain injury.
Also, powered mobility, augmentative communication aids, ADL aids, and computer and vocational access problems have been addressed. The total caseload (after 12 years) is over 1500 individuals, with an active caseload of approximately 750 clients. There are about 140 new referrals per year to the program.

FUNDING AND BILLING PRACTICES

Handouts will be provided which outline the detailed steps required to secure funding approval from private insurance carriers and government agencies, such as Tennessee Medicaid and Medicare. Suggestions and strategies will be discussed as to how to approach or develop additional sources of funding. And finally, a model will be presented which outlines the steps used to secure and maintain the funding for RET services.

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SERVICE DELIVERY
MARKETING and OPERATING in the PRIVATE SECTOR

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"Private Practice" in engineering /technology service delivery currently represents a small segment of the profession. That which is practiced is for the most part consultative in nature, however, project implementation is often necessary when adequate community resources are not available to carry out recommendations.

This type of practice generally requires a broad base of knowledge in comprehensive rehabilitation and depth in all aspects of rehabilitation engineering and technology. This is necessary because the referral patterns to private practice are extremely defuse and service requests arise from a wide spectrum of sources and disabilities. Being able to offer this type of service generally requires a good foundation in medical and vocational rehabilitation. This is needed to maintain perspective and assure the appropriate integration of technical intervention in the rehabilitation process.

In private practice one may not have the benefit of being an integral team member, however, to provide quality professional services it is absolutley necessary to understand and play that role and to establish a group of associates in the rehabilitation field.

The players in this process are; the associates, the customers i.e. the entity which pays the bills, the clients who are obviously the disabled individuals needing services and in the vocational setting the employers who are impacted by the intervention.

Most of the consulting work falls into two categories; first being education/vocation employment related, i.e. return to school or work and its associated activities or injury prevention. The second category is litigation which breaks down into the areas of liability, i.e. establishing the cause or blame for a loss or damages, i.e. determining the role and cost of technology that may be used to compensate for functional losses. These activities may be performed for either defense or plaintiff.

The customers in the education/vocation area are state agencies such as; The Division of Vocational Rehabilitation, Injured Workers/Labor and Industries, Developmental Disabilities private insurance for medical and workmens compensation and finally employers. Marketing to these customers is based in quality assurance i.e. convincing them that the dollars spent will achieve the desired outcome. What they want is assured return to work or school in the shortest period of time with the lowest total dollar expenditure possible.

Marketing is best accomplished by demonstrating examples of consistently successful interventions. The optimal method to do this is through inservices, training programs conducted by State or Regional organizations.

In the legal system there is little active marketing that is very effective because the net-work of referrals among attorneys is difficult to penetrate. There is no substitute for being identified as a good and credible witness. Consulting practices are built on referral not advertising.

Operating in the private sector one must have some form of credential that identifies them as a qualified professional. It requires background and capability in small business administration. Business licensing, and registration for local, regional, state and federal permits and taxes as well as insurance for both professional and product liability are all required. The most important fundamental aspect in operating the business is an efficient and sound management and accounting system with a well defined fee structure and billing system. Work for any customer should never be performed without written agreement to pay at established rates for consultation, evaluation, reporting, implementation, travel and sub-contracted services.

Though private practice service delivery will certainly play a role in the industry, it will likely grow slower than institutionally based programs. Private practice can be an opportune area for individuals who have good depth in comprehensive rehabilitation and technology and who also have good business capability and are entrepreneural by nature. The classic definition of entrepreneurship is; making positive change in the value of resources. This is indeed the fundamental concept of rehabilitation.

MEASURING THE BENEFITS OF TECHNOLOGY IN THE REHAB SETTING

(A Commentary From The Service Provider's Perspective)

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Applying technology in the rehabilitation setting provides unquestionable benefits to every person and organization concerned with disability issues.... but can the value of said benefits be gauged by monetary calipers alone? How does one attach a dollar equivilency to "a secure defense" or "independence for persons with disabilities"? The legislative body has been persuaded by the general public, and a myriad of special interests, that these are VALUES which are desired.....and worth having!

The advent of organized rehabilitation technology services is relatively new, and it is imperative that we (the service providers), be preparing the tools necessary to assess and document the values and benefits that science and technology contributes towards helping achieve the personal goals (and rights) of persons with disabilities.

Perhaps this newest discipline within rehabilitation, has unknowingly fallen silent victim to the traditional urge to prove "COST BENEFITS" instead of pointing to the overall benefits of our interventions. David Stockman, former Budget Director for the Reagan administration, was quoted as saying that .."vocational rehabilitation had not demonstrated its cost benefit". He may be right, but we as a society have collectively determined that the VALUE of work and independence for persons with disabilities, is a worthwhile objective....and worthy of support. If the VALUE cannot be equated with COST-SAVINGS, which offset the original program expenditures, then so be it. If society wants it, it will get "it", but first it will require a great deal of "Blood, Sweat & Tears" marketing of this discipline's contributions in helping people achieve these VALUES!

One way to unify the marketing efforts of this discipline, is to first paint a picture consisting of all who will receive "benefits" from investment in our services. We can easily prove that properly applied technology not only enhances the independence of the disabled user, but does in fact, render obvious benefits to the user's family, society in general, and rehabilitation service providers as well.

If dollars must enter the picture (an inevitable misfortune), we could perhaps easily justify the investment by first extrapolating the current cost to the above, if the technology is **NOT** provided! What would it cost an industry if it neglected to keep up with practical market demands? If the sources of capital for their research only required that they be about the business of "researching & developing", without insuring that these efforts were in fact, placing them more in line with market demands, it would die in short order. In like manner, one could kill the same company by placing all of its energy and capital into R&D, with little or none going into the development of product.

Such nightmares have plagued our discipline in its past, possibly contributing to the misconception that our technologies and services are extremely expensive, and too esoteric to provide to persons with disabilities.

I think we've learned our lesson in part. We're all now living with our belts tighter, and the benefits of our services have not been significantly diminished. We're all learning to provide pragmatic solutions to problems that formerly required steam from the Federal furnace. With no more money to burn, we are now making **TOOLS**, not **TOYS**!

Now all we have to do is make sure the right people know it. Those of our ranks in the service delivery realm, have, by sheer demand, been too busy to properly document the benefits vs. costs ratios....but we know that they can be the most impressive and effective tools to help secure funding. It would behoove our Association (RESNA) to commission the development of a standardized mechanism by which we could all determine costs (without it) vs. the benefits rendered by technology.

Will all interested statisticians please rise and be recognized??

MEASUREMENT OF EFFICACY OF TECHNOLOGY: A PARTICIPATORY PROCESS

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ABSTRACT

The design of effective equipment can be enhanced by the planning process which underlies the actual design decisions. This planning process can be itself specified and evaluated in terms of its efficacy in generating the appropriate data. Particularly crucial is the process by which client input is elicited in respect to the goals which the equipment is expected to fulfill; and the attributes which would increase the "fit" of the device.

INTRODUCTION

The measurement of efficacy of technology is an important part of any service delivery program. In each individual case; and in aggregate, the evaluative process provides data to support the continuation of the service program as well as opportunities to make such programs more adaptive.

The determination of efficacy has several aspects: the development of the outcome criteria to be used; the actual selection of the technical aids - the means considered as having the power to accomplish the effects that are sought - thus the making of a plan consisting of both ends and means. Then at a subsequent stage, there is collection of data evaluating both the outcomes achieved and the contribution of the means to those outcomes. The design of adaptive equipment is thus considered to be based upon a cyclical planning process. An initial plan is made which is then reviewed and modified as appropriate.

This planning system for the design of quipment is further considered to be a technology in its own right. The planning system can be specified and evaluated in terms of its own efficacy as a data generator. For the sake of this analysis, a three stage planning process is postulated. The first stage ends with a tentative goal statement and the selection of the major aspects of the technical means to accomplish the goals ("initial planning"). The second stage is the review during which both the initial goal and the technical decisions are evaluated so as to lead to the completion of the product ("final fitting"). A third stage is then the further evaluation of the outcomes and the means at some appropriate time after the product has been put into use ("follow-up"). In light of the ongoing quality of the client relationship, differing goals as to data collection can be established for these several stages.

WHAT ARE THE GOALS?

The initial planning stage is important as providing the basis for the entire design process. Particularly crucial is that the technique by which the initial goal statement is generated be determined to be efficacious. One criterion by which the goal statement is to be measured is its "relevance," arising out of client needs and priorities. The likelihood that the product will be deemed useful at the time of follow-up is greater to the degree it meets the needs of the user.

To establish an appropriate goal, an adequate exploration must take place of the concerns and the needs of the user. A three-fold exploration is the mechanism used before then carrying out a selection and then some sort of evaluation.

For example, in the design of an appropriate wheelchair, it is generally necessary to define several outcome criteria. One client requesting a new wheelchair, when asked about his concerns, first mentioned his concern about his chair tipping over. Then, when asked again, described the problem of maneuvering in tight places in his house trailer. Only when asked for a third time did he mention that it was particularly important for him living in a rural area to have the option of crossing an occasional short distance of gravel.

The subsequent prioritization or other measure of the relative value of these criteria depends upon this exploration phase as being adequately carried out. A "check-out" procedure is used to determine the adequacy of the exploration. If the client does not confirm that he or she has identified all the needs which the wheelchair is to fulfill, one may once again carry out exploration leading to the delineation of several other criteria.

Still another case illustrates the value of this three-fold exploration in defining need. When first asked about her concerns, a young woman with left hemiplegia mentioned her left arm weakness. When asked as to what problems were caused by her arm weakness, she spoke of her inability to care for her children. When further asked as to what sorts of things she was particularly unable to do for her children, she desribed her being unable to make their meals. The relevance of any adaptive aid would be expected to increase as these needs become more clearly defined.

An adequate goal statement must meet the criterion of "specificity" as well as "relevance." A three point scale is used to meet this criterion. In addition to the question of WHAT?, answers are sought to the setting (WHERE? or WHEN?); and some measure as to degree (HOW WELL? etc.). In the example of the man described above, a goal statement meeting the criteria of specificity would be "to be able to push my chair in the gravel near my house without getting winded."

The adequate delineation of a goal statement is crucial for the design activity to proceed. Time is usefully spent initially in order to have a measure for evaluation at later stages. Participation of the client in generating the goal from the start not only makes it more likely that the client can in turn participate at later stages but makes more likely that the results will indeed be deemed to be efficacious at follow-up.

The method by which these twin criteria of specificity and relevance of goal are met is that of maximal client participation. A scale is used to describe the level of participation elicited during the planning process. "Free choice" is when the client has the opportunity to answer open-ended questions as to concerns and goals. In essence, the client has generated the options during the exploration phase. "Multiple choice" is the condition when the client is provided several (3) suggestions from which one may choose the answers to the planning questions. "Forced choice" is when the client is provided a single recommendation to which one may or may not concur. Maximal client participation in respect to goal setting is defined as the use of "free choice" at the outset; going down the scale one step at a time, and only as necessary in order to meet the criteria of specificity; and to return to "free choice" at least once more during the course of the process.

One may note that there is no provision, at least in respect to goal setting, for a category of "no choice" wherein the client is merely told the concerns and goals to which the client is expected to "comply." It is felt that it would be inappropriate for a client to be so "prescribed" goals.

WHAT ARE THE MEANS?

The generation of data to delineate the other part of the plan - the technical aspects by which the goals are to be accomplished - may require somewhat different criteria of efficacy and techniques. There is frequently need for a higher degree of specificity so that the product can indeed meet technical requirements for efficacy. Yet it remains highly important that the technical aid "fit" the user so that it will ultimately be effective.

The process of generating data as to the means once again requires exploration before carrying out selection and then specification. Although the client is uniquely able to contribute to the exploration of needs and goals, the professional is usually uniquely able to contribute the technical knowledge necessary for the exploration of the means. The client can however contribute to the selection and specification phase.

The proper fitting of the device requires maximal level of participation of the client from the very start. It has been found particularly important to ensure such participation if high tech items are to be integrated into the user's life-space. Yet it is not infrequent for devices to be prescribed wherein no choice has been provided for clients with consequential lack of usage.

Maximal client participation in the identification of the means - the actual design of the device or its components - is defined as the use of "multiple choice" at the outset; going down the steps one at a time, and only as necessary in order to achieve specificity; and to return to "multiple choice" at some time during the interview. There may be rare instances when it becomes necessary to function at the level of "prescription" in respect to the means. In so doing, it is important to recognize that one is trading off the element of "fit" to a very great degree.

During the selection and specification phases, it is frequently necessary for the client to participate in decisions as to trade-offs in respect to costs. What are the priorities in respect to initial costs, ease in repair, and durability? Is the selection of the device to meet the goals to be based upon maximum utility, minimum cost, or some other decision rule?

Even more important is the selection of options as to the appearance of the device; and its consistency with the user's usual environment. The fit is enhanced to the degree that such aspects as size, similarity to the norm of the client's way of life and physical environment can be dealt with. Although the professional is responsible for ensuring that the device potentially has the power to do the job, whether it actually does so and be judged to be efficacious depends to a major degree on the way it is introduced to the user.

As the client increases his or her knowledge of the technical aspects, the option exists to move to a level of participation for some users which has not been yet described in the scale. The level of "independence" involves the client carrying out the planning process by both asking the questions and answering for himself or herself. The client has become an independent designer of technical aids thus contributing to the solution of problems for others as well. The ultimate criterion of the efficacy of the planning process is just such growth.

CONCLUSION

The collection of data that serves to underlie the design process has been specified. Criteria have been developed for the evaluation of the efficacy of this planning process in eliciting the necessary data with particular reference to client contribution to the "relevance" of the goal and the "fit" of the device designed to accomplish that goal.

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REHABILITATION TECHNOLOGY SERVICES: A MOBILE REHABILITATION ENGINEERING DEPARTMENT

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ABSTRACT

This paper gives an overview of United Cerebral Palsy's statewide Rehabilitation Technology Services program. This program serves individuals who are eligible for services through the state Division of Developmental Disabilities. Utilizing a mobile shop concept Rehabilitation Technology Services offers informational presentations, assistance to local center staff, as well as device modification or fabrication.

INTRODUCTION

United Cerebral Palsy Associations of New Jersey was interested in extending rehabilitation engineering services to it's affiliates and other agencies, offering services to individuals with developmental disabilities. In May of 1986, a proposal was submitted to the state Division of Developmental Disabilities which described what rehabilitation engineering services were and how they could be provided to centers and individuals elegible for assistance. The proposal explained that some facilities could readily identify the need a rehabilitation engineer while others were not as aware of the role of technology in rehabilitation. A strategy was outlined which realized the need for informational presentations as well as immediate direct services. This outline layed the groundwork for Rehabilitation Technology Services.

METHOD

Rehabilitation Technology Services is a mobile rehabilitation engineering department consisting of two vans equipped with full workshops, demonstration/evaluation equipment, and wheelchair lifts. Training, assessment, consultation, and device modification or fabrication services are offered in the following areas:

-Adapted Toys
-Mobility
-Seating Systems
-Augmentative Communication Aids
-Personal Computers and Modifications
-Environmental Controls
-Home/Living Environmental Modifications
-Vocational Adaptations

Rehabilitation Technology Services (RTS) is a two part program. The first visit to any center begins with a presentation on what services RTS offers and a demonstration on how technology can assist individuals with disabilities. This is strictly an informational session, but paves the way for direct client assistance.

RTS spends much of its time as a facilitators of discussions centered around a particular client's equipment. Rehabilitation Engineering is as much a process as it is a person. It is the technical delivery of ideas and solutions to problems identified by an interdisciplinary team. Many times a teacher or therapist will know what the outcome should be, but they will lack the technical expertise to create it.

Since rehabilitation engineering is also a process, there are many times when a rehabilitation engineer is not needed. One focus of RTS is to educate staff at centers and institutions as to when they do or don't need RTS. The selection of devices can be very simple when one is familiar with as many options as possible and has had exposure to their applications. The development and support of resident "experts" is one of the most effective ways of getting the service to the individuals who need it. The resident expert is usually a staff member at a facility who has shown interest and involvement in the application of technology to disabilities. This individual may be a teacher or therapist. The establishment of resident experts forms an effective network for service delivery throughout the state.

The staff of Rehabilitation Technology Services is comprised of three rehabilitation engineers. Each has a varied professional background which has given the program a broader experiencial base. All have had extensive experience in the modification and fabrication of assistive devices as well as computer applications and home accomodations. Centers or individuals requesting services contact the central office of United Cerebral Palsy and are assigned a rehabilitation engineer depending on geographic location(north - south).

All vans, tools and equipment used by RTS were obtained through the contract with the state Division of Developmental Disabilities. The equipment included the small bench tools for the vans(drill press, bandsaw, belt sander, and grinder), hand tools, as well as larger tools for a base shop. Other equipment included was a power wheelchair, communication aids, and an Apple computer and software. The contract also allows for supplies to be used for the fabrication of devices. The budget allocated very little money for evaluation/demonstration equipment. Much of this was obtained through donations and long term loans from equipment manufacturers.

DISCUSSION

Rehabilitation Technology Services has, over the past six months, served over 500 teachers, therapists, and parents. It has also provided direct services to over 60 individuals with disabilities. The program has grown from one van to two and one staff member to three. RTS, now, also works closely with Project H.I.R.E.(Handicapped Individuals Requiring Employment), a supported work/job placement service also administered through United Cerebral Palsy.

Is Rehabilitation Technology Services an effective way of providing services? RTS puts much of it's efforts into supporting local centers, as these are the individuals upon which continued service delivery depends. If success was mesured by the increased level of understanding of rehabilitation engineering throughout the state, then this would be a successful program(until the next large staff turnover). The method of utilizing a mobile rehabilitation engineering department is effective if it provides support and assistance to center staff. This model would not be as quickly accepted(if accepted at all) if it was a "one shot" evaluation team interested more in their goals than the goals of the facility.

Rehabilitation Engineering will continue to grow and be utilized throughout New Jersey as long as there is a continued effort to educate rehabilitation professionals to the role of technology in assisting individuals with disabilities. UCP's Rehabilitation Technology Services program continues to realize it's success not through numbers of equipment fabricated but the increased awareness in new devices and equipment statewide.

A view towards the back of one of Rehabilitation Technology Services mobile workshops.

ESTABLISHMENT OF A COMPETITIVE INDUSTRY TO EMPLOY DISABLED PERSONS: LAYOUT OF FACILITIES

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ABSTRACT

This paper presents guidelines for facilities layout which the authors consider important in a production industry in which the majority of the workers possess at least one significant disability. An efficient layout minimizes the time required to move raw materials from the place they are received, through the production process, and on to the shipping point. The flow of materials should be in one general direction, with a minimum of work-in-process storage points and flow reversals. There should be reasoning for the specific placement of everything within the facility. The three basic types of layouts: product, process, or fixed position must be understood and applied correctly. Sample layouts must be simulated on paper (or computer) showing all the required production tasks in the most efficient sequence, and all special considerations for personnel with handicaps must not create inconveniences for the other workers. The final layout should possess built-in "flexibility," that is, if a facility is to be capable of setting up production for a variety of products, set-up time and costs must be minimized.

INTRODUCTION

Any industrial facility should be arranged so as to prevent delays caused by excessive transit distances and physical obstructions. Efficient plant layout is a proven benefit in any productive operation but it borders on necessity when the majority of the workers are disabled. Strategic placement of all the components to eliminate excessive motion becomes an essential factor when most of the employees are incapable of extraneous or even "normal" motion. In addition to focusing reactively on unobstructed employee mobility and material flow, an effective facilities plan must be proactive in accommodating direct worker interfacing with tooling and equipment, which includes specific work station material handling. The plan must consider correct human engineering for positioning and posturing and must permit equal accessibility to all workers. ANSI standards and minimum federal requirements must be adhered to and it is important that the overall environment be conducive to effective communication and comfort. Input from those who will be working in the facility is imperative, therefore the layout should be developed by a team of persons representing a cross section of production operators (1), disabled and able-bodied alike.

BACKGROUND AND PURPOSE

Center Industries Corporation (CIC) in Wichita, Kansas has been markedly successful at competitively employing disabled persons, some quite severe, since 1975. CIC is a not-for-profit corporation with over 100,000 square feet of manufacturing space currently employing 130 persons; more than 90 of whom are disabled. Its annual gross sales exceeds $2.5 million and the average hourly wage of its employees is about $4.30. CIC continues to grow as a viable manufacturing facility. In fact, employment has more than doubled since 1983; gross sales have risen more than 30 percent in the past two years, and a physical plant expansion of over 30 percent has taken place in the past year. CIC serves also as a laboratory where rehabilitation engineers attempt innovative schemes to augment the physical capabilities of the handicapped workers. Consequently, it has been determined appropriate to investigate why and how CIC came to be and continues to grow and to determine how similar systems might be established and operated in other locations. Establishing guidelines for efficient facilities layout is just one of the topics being researched. The results of the research are to be presented to other organizations planning competitive industries similar to CIC and to existing competitive operations, large and small, employing varying ratios of disabled workers.

FACILITIES LAYOUT GUIDELINES

The following seven general guidelines are those which have been found by the authors to be of utmost importance in a production industry in which the majority of workers posses some level of disability:

1. There should a realization from the outset that many of the employees will be in wheelchairs, both manual and electric, or may be ambulatory but relatively slow or unstable. There will be workers with only one usable hand or with both hands severely impaired. Some employees will be blind or deaf or mentally impaired of lack verbal communication skills of have multiple disabilities. The capabilities of all the employees must be kept in mind when plant layout tasks are undertaken.

2. The earliest federal move toward the improvements of building accessibility was the Architectural Barriers Act of 1968. This Act required that any facility supported in any way by the U. S. Government must be made accessible according to standards developed. It must be kept in mind that if any industry is supported even in the least by the federal government, compliance with the

Architectural Barriers Act is an obligation.

3. There are three basic types of layouts for manufacturing or assembly facilities depending upon the type(s) of production contracts being worked. The three types are: product layout, process layout, and fixed position layout. The most common type is product layout which is used primarily in an industry that produces a relatively large quantity of specific long term products. Each product is assigned to a specific area of the plant and the sequential operations on each product determines the layout of the equipment and tooling. Explanations of the three types of plant layouts and their uses are as follows (2):

a. Product Layout
The production line is set up with the receiving of raw materials at the beginning followed by a balanced sequence of manufacturing and/or assembly steps. The layout is concluded with the packaging and shipping of the finished product.

b. Process Layout
The production contracts requiring similar processes being performed on various short-term relatively low volume products should be set up according to process layout. The process layout, also called the functional layout, is used primarily for machine shop or print shop type contracts. The equipment and tooling are located in permanent positions relative to frequency of use, and then various products are routed through the process layout in the most efficient sequence. Each product may require a totally different sequence of operations.

c. Fixed Position Layout
This type layout is used for the production of large sized low volume products. The major product components remain in one place and the tooling, equipment, and workers are brought to the worksite. The fixed position layout should be used when a significant amount of labor is required for the production of a single unit of a product. Responsibility for product quality can be assigned to a specific person or to a specially skilled crew of workers.

4. The first step to efficient plant layout is a reasonable understanding by the layout team of the products and processes. It is imperative that the team be able to simulate on paper (or computer) all the required production tasks in the most logical sequence. Product assembly charts and production flow charts for each product or process should be developed then converted to a strategic layout of the facility. Scaled and labeled cardboard cutouts of all the components may be moved about on a simulated production floor in order to arrive at the optimal layout. Once a feasible layout is established, the cutouts may be temporarily fixed in place using rubber cement and a permanent drawing made of the layout. A minimum of three sample layouts is recommended before a final decision is made.

5. Some of the special layout considerations for handicapped personnel, which must not create any significant inconveniences for any of the other workers, are the following (3)(4):

a. Minimum clear width aisleways for a single wheelchair is 3'-0". The clear width may be decreased to a minimum of 2'-8" if the passage length is less than 2'-0". All doorways must meet the 2'-8" clear width specification, however, 3'-0" doorways should be installed if at all possible.

b. "Push" operation is preferred over "Pull" on all doors, therefore, 2-way swing action is recommended. If automatic doors are not used, push or pull force must not exceed 8-lb.

c. Mimimum clearance for two wheelchairs to pass in an aisleway is 5'-0". However, experience has shown that when wheelchair traffic is quite heavy and ambulatory persons wish to pass, aisleways should provide 6'-0" clear width.

d. A wheelchair requires a space of at least 5'-0" diameter to make a 180 degree turn or a T-shaped junction of 3'-0" clear width aisleways.

e. Clear floor or ground space to be occupied by a wheelchair must be at least 2'-6" wide by 4'-0" long. A preferred area, if space is available, is 3'-0" wide by 4'-0" long.

f. A workstation for a person in a wheelchair must consist of a worktable surface height of no more than 2'-10" with clear height from the floor to the bottom of the worktable of at least 2'-8". Clear width below the table must be at least 2'-6" (2'-8" preferred) amd clear depth below the table must be at least 2'-1". Table legs or cross members beneath standard workbenches may have to be removed or relocated.

g. All floor surfaces must be covered with non-slip materials that will allow wheelchairs to be maneuvered easily and will not create any mobility obstacles for persons with limited walking capabilities.

h. Ramps must be built with a mimimum of 3'-0" clear width and a slope of no greater than 1 in 12. They must not rise greater than 2'-6" in a single run without an intermediate 5' long lever landing. Guard rails must be 2'-8" high and must be provided on ramps rising higher than 6". Below 6", the sides of the ramp must be sloped gradually to the ground. Curbs of at least 2" height must be provided along each side of the ramp unless the guard rails have vertical posts no greater than 1'-0" apart.

i. All stairways must be provided with handrails on both sides. The handrails shall no be less than 1-½" nor greater than 2" in width or diameter.

j. The facilities should be single story or wheelchair use must be limited to the first floor, unless an adequate number of accessible elevators are provided.

k. Special parking spaces must be 4' wider than standard, located most convenient to the building entrance and clearly marked. Two special parking spaces side-by-side may share the 4' extra width.

l. Restroom layout and design is much too detailed to be addressed fully in this paper, but accessibility is the key factor. A few important federal guidelines are as follows:

1) Stool height must be between 1'-5" and 1'-7".
2) Wall mounted grab bars, 2' to 3' long, should be provided on two sides of the stool at a height of 2'-9" to 3'-0". There should be no more than 1'-0" between rear of grab bar and the back wall.
3) Individual toilet stalls must be 4'-0" wide and 5'-6" deep for wall mounted stools or 5'-9" deep for floor mounted stools.
4) The toilet paper dispenser should be mounted at least 1'-7" off the floor and 3'-0" from the back wall.
5) Lavatories are to be located no more than 2'-10" from the floor to the top surface with a minimum clear height space of 2'-3" beneath the lavatory. Clear distances of 1'-7" must be allowed from the front edge of the lavatory to any rear obstruction and the lavatory bowl must be no more than 6-½" deep.

m. Further detailed federal guidelines on accessibility requirements can be received by contacting:

Office of Technical Services
U. S. Architectural and Transportation Barriers Compliance Board
(202) 472-2700

n. In order to get a reasonably accurate perspective on handicapped accessibility of an existing work place, it is recommended that a person in a wheelchair attempt to maneuver throughout the entire facility. Someone with manual dexterity, visual, hearing, and/or verbal communication impairments should attempt the same before production begins. This exercise will point out the need for specially actuated and/or lowered hand wash stations, time clocks, drinking fountains, paper towel dispensers, telephones, cafeteria tables, etc.

6. In addition to the layout of direct production areas including production management facilities, adequate space must be provided for support functions and special services, such as engineering, accounting, personnel, marketing or sales, and aide and attendant care services.

7. A term that is almost as important as accessibility is "flexibility." If a facility is to be capable of setting up production for a variety of contracts, then set up costs must be minimal. A few suggestions for keeping the facility and its layout flexible are the following:

a. Minimize the number of permanent interior walls so that basic shapes of work areas can be changed if required.

b. Decide ahead of time which areas of the plant will be used for product layout, for process layout or for fixed position layout.

c. Investing in a "computer-aided" facilities planning system might prove feasible if layout changes are incorporated frequently (5). Layouts can be drawn and altered quickly plus disabled persons might be trained to perform some of the layout functions. Systems that are relatively inexpensive and simple to operate are VersaCad and AutoCad.

SUMMATION

The layout of the facilities is conducive to the ultimate efficiency of the flow of production. A competitive industry must be accessible and flexible. It must decide early who the workforce will be and there should be reasoning for the placement of everything within the facility. Special consideration should be given to employees with disabilities but there should be no obstacles or inconveniences placed upon the able-bodied workers.

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A POWERED AIR PURIFICATION DEVICE FOR PERSONAL, PORTABLE USE BY PERSONS WITH SEVERE RESPIRATORY ALLERGIES

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ABSTRACT

People with severe respiratory allergies require some type of system to purify the air of various allergens. The air inside of buildings can easily be cleaned through ventilation systems and room purifiers. The air outside closed environments is not so easily controlled and consequently presents a barrier to people with severe allergies as they attempt to move about the community. Thus there is a need for a personal air purification device which the user carries around with him. Currently people requiring such a device use one which was originally developed for industrial use. However, these units are noisy, bulky and aesthetically displeasing for daily use. This paper describes the improvement of a device to provide better airflow.

INTRODUCTION

People with respiratory allergies require some means of protecting themselves from irritating particles in the air. Allergens such as pollen and dust cause common symptoms of sneezing and nasal irritation. Fumes such as gas and smoke are not allergens but act to aggravate existing respiratory difficulties. Also, respirastory infections are not uncommon for people plagued with allergies especially when proper treatment is not available. Generally people who suffer from allergies use two methods of control;(1) medications or (2) avoidance of offending allergens. Most people combine the two methods to reach satisfactory solutions. Occasionally medications provide no relief. In this instance avoidance is the only means of coping with allergies.

Avoidance is defined as removing harmful particles from the environment so that they are not able to irritate the individual. Removal can easily be accomplished in a closed environment where the air can be cleaned using room air purifiers or controlled ventilation systems. The environment in a car can also be controlled through the same means. However, unless a means of moving from one of these closed environments to another is provided, an allergy sufferer could easily become trapped in a bubble-like environment. Consequently there is a need for a personal air purification device which a person can take with him wherever he goes.

Currently the available devices have been developed by industry in order to protect workers from hazardous breathing environments. Unfortunately, these devices tend to be too bulky, noisy and aesthetically displeasing for everyday use. In fact, some industrial workers find the devices so cumbersome and inconvenient that they do not use them even when usage is required for their job.

An additional problem is that the devices have been developed for average to large males who have normal lung capacity. Consequently it is difficult for a small female or someone with decreased breathing ability to find an acceptable device of an appropriate weight, airflow and/or facepiece. To address these issues, the improvement of an existing air purification device was investigated with the aim of making a lighter, quieter and more powerful unit.

The client for whom this project was initiated is a small female who has been diagnosed with severe allergic rhinitis and uses a breathing assist device. Before using the device, she was plagued with respiratory infections which were becoming increasingly detrimental to her health. Since she started using the device, the incidence of infections has decreased significantly. The device is small and light but provides only enough airflow for light activities for short periods of time. Other devices on the market are heavier, noisier and do not have a satisfactory facepiece which fits her small face. The clients activities and use of the device were examined to formulate guidelines for improving her air purification device. See Chart 1.

PROBLEM DEFINITION

To increase the airflow in the present system so that more vigorous activities can be undertaken and fume filters can be used in smoky environments. As much of the original device will be maintained for aesthetical reasons and for ease of use.

CHART 1: USE OF DEVICE FOR VARIOUS ACTIVITIES

Activity	Airflow Required of Device (l/min)	Contaminants	Filter Required	Noise Level
Walking	65	pollen, dust	large particle	N/A
Concerts Church	< 65	smoke, inscence	fume	LOW
Shopping	65	smoke	fume	N/A
Gardening Outdoor Activities	90	pollen, dust	large particle	N/A

NOTES:

A. Walking is the only activity for which the client uses her present device. All flowrates have been estimated from the this value.

B. Two different types of filters are required to filter the air:
   1. large particle filters to remove dust and pollen.
   2. fume filters to remove smoke, car exhaust and inscence.

C. Fume filters on the present device reduce airflow to a level unacceptable to the client.

PROBLEM SOLUTION

Several approaches were explored in the process of achieving the goal. It was first thought that increasing the number of filters would increase the airflow sufficiently. This fact was verified, but a satisfactory means of attaching additional filters to the device could not be found. Secondly, modifications to the fan and motor were examined. These proved unsuccessful due to the limited size inside the case. Finally, the voltage supply to the motor was examined. It was noted that the motor was rated at 12V but was powered by a 6V battery. On the basis of operating the device at various voltages and measuring corresponding airflow rates, a range of voltages was recommended. See Chart 2. The recomended voltages are multiples of standard cell voltages of nickel-cadmium batteries (1.2V) and lead-acid batteries (2.0V).

It was noted that increasing the voltage might also affect noise level, current drain on the battery, and the operating characteristics of the motor and accompanying circuitry. The first two possibilities were critical issues to the client since she uses the device at social gatherings, such as concerts, and for periods of 2 to 4 hours. The client assisted in determining that the noise level was not increased above an acceptable level in a test trial. Foam insulation was added inside the case to further reduce noise. To accommodate the higher current drain, a battery with a longer ampere-hour rating was selected.

The motor was tested at a higher voltage for several hours with no appreciable increase in temperature. The circuitry which regulates motor speed was diagrammed and it was thought that the higher voltage would not adversely affect its performance. An 8.4V battery was then selected since this voltage provided maximal airflow while noise level remained minimal and the electrical components were not adversely affected. It should be noted that a larger battery could not be used due to size limitations of the device. Even to accommodate the 8.4V battery, it was neccesary to lengthen the case by modifying the battery compartment's lid.

A nickel-cadmium battery pack was assembled from seven 1.2V, 4 A-H cells. A battery connector which was compatible with the present system was used. A recharger was made from an AC to 9V DC adaptor; it was coupled with a series resistor to limit the charging current.

CHART 2: AIRFLOW VALUES (l/min)

	voltage(V)	6.0	7.2	8.4
	current(mA)	300	420	560
FILTER TYPE	2 Lg. part.	65	85	102
	2 Fume	37	65	79
	4 Fume	60	-	-

RESULTS

The total cost of modifying the unit was less than $150.00. A fee of $225.00 was charged to the Department of Rehabilitation Services in Virginia to cover the cost of consultation and modification. The client was very pleased with the increased airflow and felt that it would increase her independence in the community. There is also the possibility for employment outside the home.

DISCUSSION

At this time there are not very many people who require breathing-assist devices for control of their allergies. However, use of these devices may prove to be a less costly than other means of allergy control if more acceptable devices are available. Additionally, industrial workers may also choose a device like the one this client uses over the more cumbersome units they now use. Hence, it seems that the availability of an 8.4V battery pack with this system would be beneficial to a number of potential users.

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CONSIDERING SOCIETAL COSTS IN JUDGING THE PERFORMANCE OF PREDICTIVE MODELS OF LOW BACK PAIN DISABILITY

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ABSTRACT

Traditionally the performance of predictive models has been measured on the basis of misclassification rates. However, an important consideration in determining the accuracy of predictive models is the cost associated with different classifications. In this study, the performance of models to predict low back pain disability was compared to actual predictions from a group of physicians in a low back clinic on the basis of the costs associated with the misclassification of patients (predicting they would be disabled but in actuality were not, and predicting they would not be disabled, but in actuality were). Through computer simulations, the different costs associated with these classification errors were varied, as was the effectiveness of medical intervention. The results were that at a low level of treatment effectiveness, there was no difference between models or between models and the physicians' predictions. At a high level of treatment effectiveness, while no difference in performance between the models and the physicians' predictions was observed when the associated costs were low, as the costs increased, the two models generated more cost-effective predictions than those made by physicians, with the empirical model providing the most cost-effective classification.

INTRODUCTION

The socioeconomic impact of low back pain (LBP) disability is substantial, and the associated costs are high [1,2]. To address this problem, we have developed a model to predict low back pain disability [3,4]. Since timely intervention during an LBP episode could prevent disability and thus be cost-effective, it is important to be able to identify those patients who are at risk of being disabled due to LBP. Elsewhere we have described the development and testing of a set of models to predict LBP disability [3]. The purpose of this article is to discuss how to evaluate the performance of different predictive models.

Traditionally the performance of predictive models has been measured on the basis of misclassification rates. However, an important and seldomly-used consideration in determining the performance of predictive models is the costs associated with different types of sensitivity of the predictions over a wide range of treatment effectiveness. This figure is representative of the success rate of intensive low back disability rehabilitation centers such as the PRIDE institute in Dallas, Texas, or the New England Back Center in Burlington, Vermont.

Ratios were used to weight the relative costs of each cell in the classification matrices, i.e., to assess the relative costs to society of each type of patient (Table 2). The values selected were 1:5, 1:10, 1:20 and 1:30, each expressed as the ratio of the cost of each false positive (FP) classification (patients predicted to be disabled, but are actually working) to the cost of each false negative (FN) classification (patients predicted to be working, but are actually disabled). Thus, at a cost ratio of 1:5, the costs associated with failing to predict, and thereby failing to treat, disability are five times as high as the costs associated with predicting disability and treating the patient when disability would not have occurred.

Reduction in costs to society will occur not by merely identifying the disabled, but by applying appropriate treatment to prevent the course of disability. Therefore, the costs associated with all patients predicted to be disabled (TP and FP) include the cost of follow-up treatment to reverse the course of potential disability (treatment costs). The cost for patients who are predicted to be working (TN and FN) does not include treatment costs. It is also assumed that all patients who do, in fact, become disabled (whether correctly predicted or not) will incur costs to society of lost productivity and compensation. From these assumptions it is obvious that those patients correctly classified as disabled (TP), but for whom treatment was ineffective, will incur all three types of costs, and hence, will be the most costly type of patient. Thus, the cost associated with this group is a function of the rate of medical effectiveness (since merely correctly identifying this group does not reduce the cost to society), in addition to the costs of misclassification. The final group, those patients predicted to be working and actually working (true negatives or TN), incur no costs to society (Table 1).

These cost ratios were applied to the four sets of predictions--physician's predictions, expert predictions, and predictions from two variants of the empirical model--at the two levels of treatment effectiveness. One of the variants of the empirical models factored cost into the discriminant function by altering the prior selection misclassification. In predicting disability, two types of misclassification errors can occur: (a) predicting disability for patients who, in actuality, do not become disabled (false positives or FP), and (b) failing to predict disability for those who do become disabled (false negatives or FP). Different costs are associated with these two types of misclassification, with the latter being much higher (Table 1).

METHODOLOGY

All patients with low back pain who were new to the Vermont Low Back Clinic and between the ages of 18 and 65 were considered for this study. However, patients who were unemployed, or who had never worked, were considered ineligible. At their initial visit, data on factors predictive of disability were collected form the study participants. Six months following the initial visit, the patients were contacted by telephone to determine their work status. Patients who were not holding a job at the follow-up were classified as "disabled", whereas all others were classified as "working." Ninety-two patients met the study criteria and were available for follow-up.

Four sets of disability predictions were used in this analysis. One set of disability predictions was made by attending physicians, one set came from an expert-based predictive model, and two sets came from models derived empirically from the data collected from the patients on their initial visit. The expert model was developed by a panel of six experts in disability, low back pain, and psychology. The empirical models were obtained through discriminant function analysis. The set of disability predictions made by the physicians can be viewed as a base rate. (See Reference 3, this volume, for a complete description of the models.) The working/disabled classifications given by the four sets of predictions were compared to the actual working/disabled classification determined at the six-month point.

Next, two levels of treatment effectiveness and four cost ratios were investigated. A figure of 25% medical effectiveness was assumed to represent current, standard treatment. This figure means that given the current treatment procedures for low back pain, of all patients correctly classified as being at high risk of becoming disabled, and then treated, 25% will return to work. The second level of treatment effectiveness selected (80%) was chosen to test the probabilities of the two groups by including the actual sizes of each group as a function of the cost information. For each empirical model, the discriminant score varied according to the cost ratio. In other words, each analysis performed at each cost ratio used a different optimal discriminant score as the minimum value for disability. For consistency with the empirical models, the selection of cutoff for the expert model was the one that minimized costs.

RESULTS

At 25% treatment effectiveness, the difference in cost between the four sets of predictions (Figure 1) is negligible. Each set of predictions shows cost increasing linearly as the cost ratio for misclassification increases. At 80% treatment effectiveness, some differences between the models become apparent (Figure 2). At lower cost ratios, differences between the models are minor, but as the cost ratios increase, the empirical model classifies the data better than either the expert model or the physicians' predictions. Further, at low cost ratios (1:5) the cost estimate for all models at both levels of treatment effectiveness are similar. As the cost ratios increase, the cost estimate at 25% treatment effectiveness is nearly double the estimate at 80% treatment effectiveness. When treatment effectiveness is high (80%) the analyses also show, not surprisingly, that changes in cost ratios have less impact on total cost than when treatment effectiveness is low.

DISCUSSION AND CONCLUSIONS

At 80% treatment effectiveness, there is a great difference between the physicians' predictions and the other models as the cost of disability increases. The reason for this is that the physicians' classification matrix was used for all cost ratios, whereas for the other models, different classification matrices were used for each cost ratio (the ones that minimized total cost at each ratio). Thus, in this study the physicians' predictions of LBP disability was assumed to be insensitive to changes in relative costs, i.e., that the physicians classify individuals independently of cost considerations. This study indicates the importance of considering the costs associated with misclassification errors in evaluating the performance of predictive models and suggests, if the assumption of insensitivity to costs is correct, the importance of making physicians aware of the cost-effectiveness of medical treatment.

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Table 1. Classification terminology and types of costs.

		PREDICTED	
		WORKING	DISABLED
ACTUAL	WORKING	TRUE NEGATIVES (TN) No costs	FALSE POSITIVES (FP) Treatment Costs
	DISABLED	FALSE NEGATIVES (FN) Lost productivity and Compensation Costs	TRUE POSITIVES (TP) Lost productivity Compensation and Treatment Costs

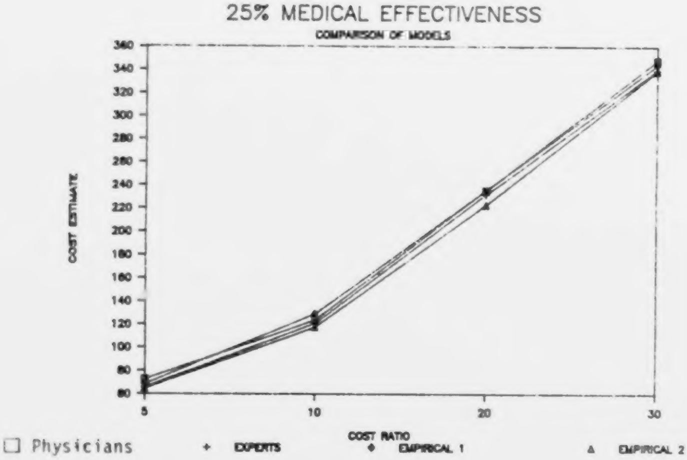
Table 2. Relative costs of classification.

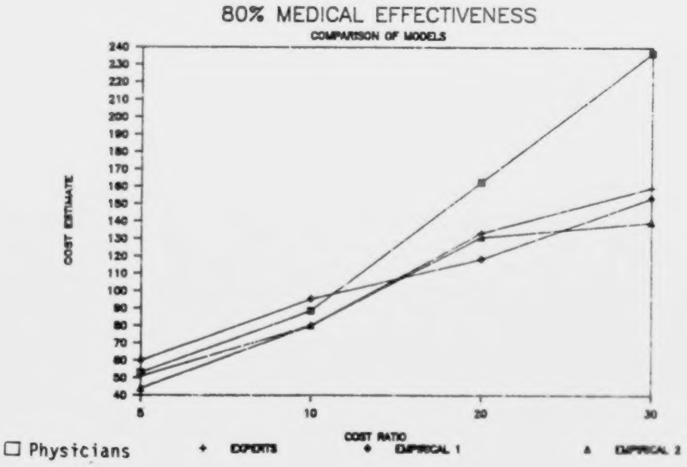
Cost Ratio	TN	FN	FP	TP[a]
25% Treatment effectiveness				
5:1	0	5	1	4.8
10:1	0	10	1	7.8
20:1	0	20	1	15.2
30:1	0	30	1	22.8
80% Treatment effectiveness				
5:1	0	5	1	2.0
10:1	0	10	1	2.8
20:1	0	20	1	10.0
30:1	0	30	1	6.8

[a] Calculation of cost ratio for TP:

$$TP = (FN \times E) + ((FN + FP) \times (1 - E))$$

where E represents the treatment effectiveness.





INITIATION OF ADAPTIVE EQUIPMENT SERVICE AT THE CLEVELAND CLINIC FOUNDATION

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The Cleveland Clinic Foundation

ABSTRACT

The department of Orthotics and Prosthetics at the Cleveland Clinic Foundation began an adaptive equipment service in 1985. The service focused on wheelchair prescription and custom seat inserts. The clinic team consisted of a Physical Therapist, Occupational Therapist, Prosthetist and fabrication technician. Recently the service has been expanded to include Rehabilitation Engineering to meet an increased number of referrals.

INTRODUCTION

The Cleveland Clinic Foundation began an Adaptive Equipment Clinic in April, 1985, to fulfill the need of the disabled for increased function and mobility. Although most referrals were from within the greater metropolitan area of nearly 2 million, service has been provided for clients referred to the Foundation from within the northeastern region. The established system has integrated adaptive equipment needs including wheelchair prescription, custom seat fabrication and delivery, and alternative positioning equipment.

METHODS

The Adaptive Equipment Clinic was housed in the Division of Prosethetics and Orhtotics with the team consisting of a prosthetist,a physical therapist, an occupational therapist, and a fabrication tech-nician. A speech pathologist and a social worker were also available upon request. In October 1986 the service has been reorganized and expanded to meet the demands of an increasing number of clients. The expansion included the addition of Rehabilitation Engineering and new facilities within the Department of Musculoskeletal Sciences. Prosthetists remain available for consultation and a full-time technician with complete fabrication facilities has been added. In this paper, however, only the clinical activities of the first eighteen months are reported.

The clinic met one day per week as needed. On the first visit an initial evaluation was performed. This consisted of an interview of the client, family and primary therapist (when available), a medical history, a review of present therapy and equipment, and a discussion of functional goals. The client was then evaluated for ROM, contractures, sensation, active muscle control, muscle tone, functional skills (transfers and ADL), and postural abnormalities. The evaluation ended with a team discussion (including the client and family) of the options and recommendations, establishment of goals, and the plan for service. Funding for the service was defined through client finance or third party payers and a return visit was scheduled for fitting and delivery. After prior approval of funding the ordering and fabrication was initiated.

The options for seating included manually constructed hard or soft foam supports, foam cushions and wedges, lateral trunk supports, and head supports. A custom molded system using an inhouse dilantency casting was also available and fabrication followed using carved foam on plywood.

RESULTS

Service was provided for individuals with various types of disabilities. Table I shows the client population and their ages and range.

TABLE I Client Populaton.

Type	No.	Follow - up Visits	Mean age / Range in Years
C.P.	10	55	16.0 /4 to 32
M.D.	2	3	15.5 /7 to 17
Myelo.	3	5	17.6 /7 to 33
Other	6	22	24.3 /9 to 38

Table II shows the type and numbers of assitive equipment provided.

TABLE II Equipment Delivered.

Type	No.
Wheelchairs	
Manual	14
Powered	2
Seats	
Molded Insert	12
Cushion and back	5
Bedding	
Sidelyer	1
Positioner	1

CONCLUSION

The service discribed operated from April, 1985 to September, 1986. Follow - up evaluations are in progress - the longest being 18 months. Most of the reported problems occured as a result of funding delays and the subsequent delay in fabrication. An increased number of referrals from within the Foundation and regional hospitals demands continued improvement of services through the newly established Rehabilitation Engineering Clinic.

Within the first six months of operation the Rehabilitation Engineering Clinic has provided services for fifty six clients. The clinic continues to provide wheelchairs, custom seating systems, and design adaptive seating equipment for the disabled in Northeast Ohio. The service also evaluates and prescribes or designs supports for hospital patients to reduce risk of pressure sore formation. Members of the clinical team are interested in providing equipment for the disabled athlete and musician. The integrated approach to adaptive equipment at the Cleveland Clinic has been successful and will continue to expand to meet the needs of the disabled population in this region.

ACKNOWLEDGMENT

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RESEARCH VS SERVICE DELIVERY:
YOU CAN HAVE YOUR CAKE AND EAT IT TOO

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ABSTRACT

This paper reports on a database designed to provide the information required to support the research proposed and additionally support a set of billing programs created for the Program Services department at the Timbers providing the attendant care services. The continued maintenance of this base is accomplished by the Program Services department through the billing process and is provided free to the research program through the personnel time saved in the billing process. The corresponding information for previous years for which data is available is purely of research interest and is proposed to be accomplished under the research grant.

INTRODUCTION

A database system has been created for the PC or XT compatible computer comprised of the quantity of attendant care provided in 16 categories for people with disabilities living at the Timbers, a 100 apartment handicap accessible complex. Funding agencies which support research such as NIHR typically do not support components of projects which are viewed as service delivery. The creation and maintenance of a database of attendant care provided requires considerable personnel time for data entry and is usually viewed as service delivery. An extensive database of this information linked with a second database of client specific information, however, is required to accomplish the research proposed and was designed under a State of Kansas supported grant which required service delivery.

The client specific database is currently being designed and will be linked to the previously implemented database of attendant care as provided in each of 16 categories and will allow correlation of the quantity of attendant care provided in each category with the disability type and level of the clients or tenants living at this facility. The goals of this research are to determine the expected type and frequency of attendant care a person with a particular disability can expect for an independent lifestyle and the prescription of devices to assist in or decrease this expected need.

BACKGROUND

The Cerebral Palsy Research Foundation of Kansas (CPRFK) in cooperation with The Wichita State University (WSU) College of Engineering has a grant with the National Institute of Handicapped Research (NIHR) to establish a Rehabilitation Engineering Center (REC) to do research in the core area of "Modifying the Worksite to Enhance Employability". In response to the research accomplished, CPRFK started Center Industries Corporation (CIC) both as an opportunity for employment for persons with disabilities and as a laboratory for the research being carried on.

It has been the philosophy of CPRFK that housing is a crucial element in the whole life environment of any individual. To provide more opportunities for independent living to people with disabilities in the Wichita area, an accessible apartment complex, Timbers, was initiated by CPRFK. This HUD supported housing project consists of 100 apartment units spread over a 10-acre site in the city. The 24 one-bedroom apartments comprising the congregate area are reserved for the most severely handicapped individuals who require some form of daily attendant care. The remaining 76 units are in four-plexes or six-plexes surrounding the congregate area and are one-bedroom and two-bedroom apartments. These are for the less severely handicapped persons who contract for attendant care on an as-needed basis. All are built for autonomous living and complete accessibility throughout the apartment unit and between apartments. In order to validate the research concepts related to independent living, the REC utilizes this facility as its laboratory. Many of the tenants living at Timbers participate in the research projects of the REC; many also work at CIC.

The population served by the REC primarily consists of brain damaged individuals, developmentally disabled or through trauma. Persons served are primarily those individuals with cerebral palsy; however, persons with multiple sclerosis, muscular dystrophy, Friedreich's Ataxia, spina bifida, and post trauma brain damage are also served. The population consists of normal to near normal intelligent individuals who desire the independence that a job and their own apartment afford.

PROBLEM DESCRIPTION

The outlining method by which it was possible to achieve a delicate balance between research and service delivery is summarized in the following steps. First it is important to know the needs of both groups. Research will require specific pieces of information. For instance it was required that a client's attendant care information be collected to observe possible trends or patterns. Therefore all corresponding information reflecting a client's attendant care was collected as research information. On the other hand, the Program Services Department at the Timbers required attendant care information and a system by which clients could be billed. This fell under the category of service delivery. The need was also expressed by Program Services for a system by which weekly, monthly, quarterly, and yearly attendant care summary reports could be produced. The needs of both groups were different.

The next step was knowing what information was available. This required a careful examination of any attendant care data sheets or other forms of documented client information. It was found that attendant care information was collected weekly using hand written service tally sheets. These sheets recorded how many times a client used a particular service during a particular week. Each service required a unique amount of time, usually measured in minutes. These sheets were then hand calculated and the client was billed based on a hourly rate. The hand written tally sheets represented a clients attendant care record. The only other information available was the individual client file and any information provided by other research studies.

APPROACH

To respond to the needs of both research and service delivery, a fast, compact, low cost system was required. This system would have to adapt easily to any changes made in the future. The decision was made to use a database system based on the following considerations. A database has the ability to expand. If in the future a field is needed it can be added to the existing data file. Similarly, if an additional data file is needed it can be added to the database. This flexibility was a major reason a database was chosen. A database also offers the ability to restrict data entry. The user is restricted to a particular field or fields. The choice being left up to the system designer. Data entry can be further stipulated by allowing only a particular data type to be accepted. The four data types being character, numeric, date, and logical. In addition, the data can be formatted in a variety of ways. Data Base III, a database management program developed by Ashton-Tate for the IBM PC and compatibles, offers the designer any combination of twenty one different options. All of the features mentioned above can be achieved by using a spread sheet.

The main reason for choosing a database as opposed to a spread sheet was the following. A database ,particularly a relational database, has the ability to link data files according to a key expression. The Attendant Care Database System for example, uses a client code to link two data files together. This link provides access to the client's personal file and the attendant care data file. This allows us to form conclusions relating a particular disability to the amount of attendant care needed. Although all of the above mentioned criteria are valid for choosing a data-base, the ability to link any number of data files is a deciding factor.

The next step was to carefully plan the structure of a database, to utilize this information and meet the needs of both groups. The first database file was created to fulfill the need for research information on attendant care and also double as a database file with which programs would interact to obtain the weekly information for billing purposes. This weekly database file, Week.dbf, contained six fields. The client code, the service, number of times the service was performed, number of days out of a week that service was required, a comment field, and a billing code. Using these six pieces of information it was possible to construct an attendant care history for a particular week. This same information would be used to generate a weekly billing sheet. The weekly database files were then appended into a larger database file called the main database file, Main.dbf. Each week the attendant care record was entered into the Week.dbf, a computerized billing sheet was generated and nothing had to be calculated by hand. The entire process of entering all of the weekly attendant care information and obtaining a printout takes approximately one hour. Compared with the older method using hand calculations and a typewriter which took an entire day. A considerable amount of personnel time was saved. In addition to generating a billing report, the larger main database file was slowly being formed week by week. This database file would later be used for research purposes. Your cake is being made. This is only one example of where, by carefully planning the structure of a database, both research information and service delivery were obtained.

SOLUTION ACHIEVED

A database system has as its core the database comprised of data files. These files contain the basis for any conclusions and it is upon this core that the application software is to be written. Without this software, you would have nothing but raw data and the software plays a vital part in the overall database system. It was once said "The sum total of any societies knowledge can be summed up in its language." I believe this also applies to application software.

Once the database has been created, the application software has to be developed. This is probably the most important step. A database system allows the designer to write application software which consists of the programs that work with the database files and it is these programs which allow information to be entered and revised easily and produce the desired reports or summary sheets. This software will not only manipulate the data but will guide the user through what otherwise might be a complicated means of data entry. This allows the system designer to create a user friendly system by which data can be entered without the use of complicated manuals or other guides. They act as a buffer between the database and the user. If someone is going to enter information, thus creating your database, they will continue to do so only if it saves them time and effort. In other words if your database is being created for you it is only because your application software allows someone else to do their job faster.

The ease of which your system can be used is just as important as the speed of the system. The system should be designed so that only minimal computer training is necessary for its operation. The system presently in use is fully menu driven requiring the operator to merely press a key for the operation desired. The user is placed in the operational environment of their choice and upon completion is returned to system menu. This again is all made possible by application software.

The final step in creating the bridge between research and service delivery is providing a means for client confidentiality to be preserved. In many cases this will have the foremost priority. The present system was designed in the following manner. Each client is assigned a random alpha-numeric code that is used when entering information on that client. All database files reference a particular client using this random client code. Therefore the Main.dbf and Week.dbf contain client information pertaining to a client code. The information is available for research purposes and the client identity is never disclosed, only the client code. On the other hand the billing reports and summary sheets provided for service delivery required that the client be identified. In other words the cake was there, but there were problems when you wanted a bite. The solution was in the creation of a database file linking the client code to the client's true identity; it was called the Passport database file. The Passport file was created as a hidden file and was locked and filed with the other client files. Thus the client confidentiality was preserved and everyone enjoyed their cake.

SUMMARY

By using the outline described, it was possible to obtain the needed attendant care and client databases for research by the Wichita REC, funded by NIHR (now NIDRR), and have it maintained through service delivery by the Program Services Department, funded by the State of Kansas. Both sides benefit, service delivery has the power of a database to produce attendant care quarterly and yearly reports or quick summary information. While at the same time researchers have a growing database that is revised and maintained at no expense, for their research needs. It is truly possible to have your cake and eat it to.

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A TRANS-DISCIPLINARY TRAINING MODEL FOR REHABILITATION TECHNOLOGY SPECIALISTS

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ABSTRACT

Application of rehabilitation technology in vocational, educational and independent living situations requires professional staff with both technical expertise and rehabilitation service delivery skills. The training model presented involves developing a "specialist" trained in both traditional rehabilitation service delivery as well as many of the technical competencies from the engineering/technical field. The focus of the concentration is to develop versatile professionals with solid technical knowledge and skills in the rehabilitation technology area who are also capable of working well with disabled persons through skills in counseling, case management, vocational assessment and others.

It is anticipated that through the availability of rehabilitation professionals that are skilled in both technology and human services, the applications of technology to assist persons with disabilities will be improved and expanded.

INTRODUCTION

The task of delivery of efficient and effective rehabilitation technology services to the broad range of individuals with physical and mental disabilities requires expertise and contributions from professionals in many varied fields. It has been well documented that the team approach utilizing expertise from medicine, rehabilitation and engineering has been effective in developing rehabilitation technology as an important service component.(1) The 1986 Rehabilitation Act has for the first time specifically recognized rehabilitation (engineering) technology as a distinct component of the rehabilitation process. A critical issue for the rehabilitation field is the need to develop staff who can most effectively utilize the resources and capabilities that technology has made available.(3)

Rehabilitation technology represents a very key resource in the overall delivery of services to persons with disabilities. There are many problems, however that limit the effectiveness of the application of technology to assist these persons. Problems range from a general lack or awareness on the part of employers and the general public on the capabilities of persons with disabilities, a lack of specific training by human service providers in the application of technology to solve problems encountered by persons with disabilities, a shortage of qualified rehabilitation engineering and technical staff and a general feeling that often questions the appropriateness of technological devices to solve problems.(3,6)

Current training activity

There is currently very little training activity in the fields of vocational rehabilitation or rehabilitation engineering to prepare professionals to utilize technology to assist the disabled person with vocational and independent living needs. A review of literature, and survey of national leaders in both the rehabilitation engineering and vocational rehabilitation fields, has found limited training resources that deal with technology and persons with disabilities.

Training programs that are established on a medical model, such as those in biomedical engineering and occupational therapy, are usually not sufficiently geared to functional vocational outcomes or processes. Training programs in the traditional vocational rehabilitation areas also have serious limitations in preparing staff to utilize technology effectively since these curricula have very little course work dealing with technology applications to persons with disabilities.

In reviewing bachelors level training programs none were found which offered a degree in rehabilitation engineering or anything specific to technological applications to disabled persons with the exception of one occupational therapy program. A master's degree program in rehabilitation engineering that is biomedically oriented exists at the University of Virginia-Charlottesville. Review of pre-service training projects sponsored by Rehabilitation Services Administration revealed only two other projects that indicated any programming dealing with technology applications to the disabled (RSA,1986).

DISCUSSION

The expertise and body of knowledge that has been developed through rehabilitation engineering and in the field of rehabilitation technology is significant. One very apparent issue that has been identified however is the lack of familiarity that the engineering and technically oriented community has of the service delivery models utilized in the rehabilitation field. Most engineers entering the field of rehabilitation engineering are well schooled in their respected engineering discipline. However, they often lack preparation in the problems and needs of the disabled or the delivery of rehabilitation services.

Need for service delivery personnel

The need for increased utilization of rehabilitation technology resources to help meet the needs of the large number of persons with disabilities is evidenced in national, regional and local needs assessments.(3,5,7) The data provides evidence that there is a need for pre-service training of individuals to deliver comprehensive rehabilitation services, including rehabilitation technology, to the large population of non-working and underemployed disabled.

Personnel available to provide assistance with specifying and fabricating adaptive equipment, modifying work stations, and designing of assistive devices are limited in number. Clinical rehabilitation engineers are normally available at Rehabilitation Engineering Centers, medical rehabilitation hospitals and occasionally with state agencies such as Vocational Rehabilitation. A limited number of rehabilitation engineers also work on a consultation basis in many states in the United States. These numbers however are not sufficient to provide outreach services to the number of persons with disabilities who need assistance. A noticeable gap still exists between the expertise of the clinical rehabilitation engineer, the medical team and the direct service providers in schools, rehabilitation facilities and state agencies. This becomes increasingly apparent when vocational applications of rehabilitation technology resources are needed. (3)

A survey of rehabilitation facilities in Region V was conducted to determine the need for vocationally oriented rehabilitation engineering specialists. Results from the survey showed a majority felt that technology related services would benefit their clients.

On a statewide basis Wisconsin, Minnesota and surrounding states have limited resources and rehabilitation technology service delivery programs to effectively meet the needs of disabled citizens. This situation is typical to most states. Survey results from the IRI study on Rehabilitation Technologies indicate that service delivery capabilities for rehabilitation technology are limited in almost all parts of the United States (5).

The recognition that greater emphasis needs to be placed on the actual delivery of services has been receiving considerable attention by Rehabilitation Services Administration (RSA), National Institute for Disability and Rehabilitation Resources (NIDRR) and professional associations such as the Association for Advancement of Rehabilitation Technology (RESNA). Priority is being placed on the development of effective models for the delivery of rehabilitation technology services and identification of personnel available.

APPROACH

The objective of this pre-service training program is to develop rehabilitation technology specialists who are able to effectively utilize the resources and capabilities of rehabilitation technology in delivering rehabilitation services in vocational, educational and independent living settings.

Training Model

The basic concept behind the rehabilitation technology specialist involves the training of a professional staff member that combines the knowledge and skills of personnel trained in vocational rehabilitation service with the practical, hands-on skills of a "technician" or "engineer". Functionally this individual serves as a connecting link between the rehabilitation service delivery community and the technical work of the engineer. The rehabilitation technology specialist is trained as a technician capable of producing/developing actual devices, making modifications and adaptations of equipment and environments, being knowledgeable of current developments in technology, capable of making referral to appropriate resources/specialists and able to interact effectively as part of the rehabilitation service delivery team.

This Rehabilitation Technology Specialist functions as one consultant to the rehabilitation team that works with persons with disabilities to identify ways to overcome, or at least minimize, physical limitations. Working with rehabilitation counselors, physical and occupational therapists, special education teachers, rehabilitation engineers, and others, the Rehabilitation Technology Specialist is responsible to come up with practical applications of technology that actually work. Duties and responsibilities for the rehabilitation technology specialist are varied depending on factors such as the specific population being served, setting, and other rehabilitation professional staff available.

In addition to being able to "specialize" in this type of work, this training model also includes skill preparation in counseling, vocational evaluation, work adjustment or many of the other human service tasks. This flexibility is important in most employment settings (5).

Curriculum

The curriculum makes extensive use of general studies and rehabilitation studies from the four year B.S. Program in Vocational Rehabilitation. The Rehabilitation Technology Specialist concentration is comprised of specialized courses in rehabilitation technology and a broad range of general technology related courses. Areas covered include materials and processes, fabrication methods, drafting, design, electricity/electronics and selections from pneumatics, hydraulics, plastics, microprocessor and computer applications and other areas.

General Studies	44-48 credits
Rehabilitation Studies	49 credits
Free Electives	4-8 credits
Rehabilitation Technology Specialist Concentration	32 credits
Total	130 credits

TRANS-DISCIPLINARY TRAINING MODEL

The training model for the Rehabilitation Technology Specialist involves a cooperative exchange of content and resources between the Schools of Education and Human Services, School of Industrial Technology, and School of Liberal Studies. This interaction between the various programs housed in these Schools provides the student with a broad based experience in application of technology to disabled persons.

CONCLUSION

There is currently very little training activity to prepare professionals to utilize technology to assist the individuals with disabilities with their vocational and independent living needs. Initiated in the Fall of 1984, the Rehabilitation Technology Specialist training program at the University of Wisconsin-Stout has established a pre-service program that will provide the rehabilitation field with staff qualified in both rehabilitation service delivery and rehabilitation technology. This program is geared to meet critical man power needs in the VR system, rehabilitation facilities, schools, and in the private sector.

The emergence of the Rehabilitation Technology Specialist as a key member of the rehabilitation team is becoming more and more recognized. This "specialist" will not replace or eliminate the need for rehabilitation engineers. Instead it is anticipated that through the availability of rehabilitation professionals that are skilled in both technology and human service, the applications of technology to assist persons with disabilities will be improved and expanded.

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EFFECTS OF ORIENTATION TO THE BODY AND INPUT DEVICE ON TASK PERFORMANCE

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ABSTRACT

The effects of hand superiority, gender, and orientation to the body on performance times were investigated for an ablebodied norm group (AB) and a group of individuals diagnosed as having cerebral palsy (CP). The evaluation devices were discrete activation switches, rotary input devices, and a fixed point movement time evaluator. The switches and rotary devices were evaluated in five orientations to the body. The general findings indicated that the standard rules-of-thumb used to design work settings for the able-bodied are, in some cases, in error. The overall mean trends were the same for AB and CP groups, indicating that the same biomechanical principles are in effect. The CP group showed lower performance levels, greater variability, greater positional sensitivity for switches, and greater device sensitivity for all devices. The performance of individual CP subjects was not well described by their group norms, indicating that specific subject capability is a critical consideration for successful task design.

INTRODUCTION

The design of work environments for individuals without significant disabling conditions is most frequently done with little rational consideration of the available design alternatives. Since individuals with disabilities generally demonstrate greater sensitivity to task configuration than do ablebodied individuals, device and position effectiveness information is of even greater importance for this group.

METHOD

Subjects

The able-bodied subjects (AB) consisted of 100 subjects (50 males, 50 females) between the ages of 20 and 49 years. The group of individuals diagnosed as having cerebral palsy (CP) consisted of 32 subjects between the ages of 22 and 34. This group was selected such that a majority of them lived in a supported environment but required minimal attendant care. Fifteen of these individuals were employed in a supported work environment. Subjects were excluded if their involvement was such that they required significant attendant care.

Apparatus

The Available Motions Inventory (A.M.I.) test package (3, 4, 5) was used to collect performance data. This evaluation system was designed to quantify levels of functional ability for the upper extremities.

Switch manipulation time and rate data were collected with a manual stop watch. Movement time to the device being evaluated was not recorded. All subjects were tested in the seated position. Hand superiority was empirically determined from the normalized performance scores for both hands on all A.M.I. tasks. The hand with the higher mean z-score was identified as "superior" and the lower was identified as "inferior".

Individual tests were mounted in panels that could be located in a variety of positions. Two classes of devices were evaluated, rotational input and switch activation. The rotational input devices were: crank (CR), a 7" diameter free rotating crank; balanced crank (BC), a 3" diameter free rotating balanced crank; and a hand knob (HK), a 2-1/2" diameter scalloped hand knob. Subjects were instructed to rotate each of these devices as many times as possible in a 10 second interval. The number of rotations was divided into 10 to derive the measure of performance -- average seconds/rotation.

The switch devices evaluated were rotary detents (DT), toggles (TG), and push buttons (PB). The rotary detent panel contained 10 rotary detent switches, each with 10 equally spaced click-stop settings. Above each rotary detent switch was a number between 1 and 9, at which that switch was to be set by the subject. The total time required to make all 10 settings was measured and used to calculate the average seconds/setting. The toggle panel consisted of 27 three way (up-off-down) toggle switches, 18 of which were to be manipulated by the subject. Above each of the switches was an indication of the setting that was to be made. Average seconds/setting was calculated. The push button panel contained 27 push buttons, equal numbers of randomly ordered red, green, and blue buttons. When a button was depressed, the button was illuminated. The subject was instructed to depress all buttons of a particular color and the total time to do so was measured. Average seconds/activation was calculated as the performance measure.

The positions for testing the various devices were standardized as follows:

Center Lower Horizontal (CLH), a horizontal work surface located at seated elbow height with its center at 75% of functional reach.

Side Lower Horizontal (SLH), a horizontal work surface located at seated elbow height 20" lateral to the CLH position and 45 degrees to the frontal plane.

Center Lower Vertical (CLV), a vertical work surface located 6" above seated elbow height and at 90% of functional reach.

Center Upper Vertical (CUV), a vertical work surface located 18" above seated elbow height at 90% of functional reach.

Side Upper Vertical (SUV), a vertical work surface located 20" lateral to the CUV position and 45 degrees to the frontal plane.

The fixed point movement time evaluator measured the time required to move 12" in four directions in the horizontal plane in response to an auditory stimulus. The directions were: lateral reach (**LR**), transverse reach (**TR**), lateral move (**LM**), and transverse move (**TM**).

RESULTS

Three way Analysis of Variance was performed for each of the test devices. The effects considered were; Gender (**G**) between subjects, Hand (**H**) superior or inferior within subject, and Position (**P**) within subject.

ANOVA SUMMARY

DEVICE	G	H	P	GxH	GxP	PxH	GxPxH
CR	**	**	**	--	--	*	--
BC	**	**	**	--	--	*	--
HK	**	**	**	--	--	*	--
DT	--	**	**	--	--	**	--
TG	--	**	**	--	--	*	--
PB	--	**	**	--	--	--	--
RT	**	*	**	--	--	--	--

* $p<0.10$
** $p<0.01$

This analysis indicated that tasks requiring rapid motion of the entire arm (CR, BC, HK, and RT) were performed at significantly different rates for males and females. Tasks involving finer dexterity did not indicate such a gender effect. Performance was significantly affected by the hand tested (Superior or Inferior) for all devices evaluated. The orientation of the device to the seated subject (Position) also indicated that it significantly affected performance for all devices. There was also a statistically insignificant but consistent interaction effect between hand superiority and position.

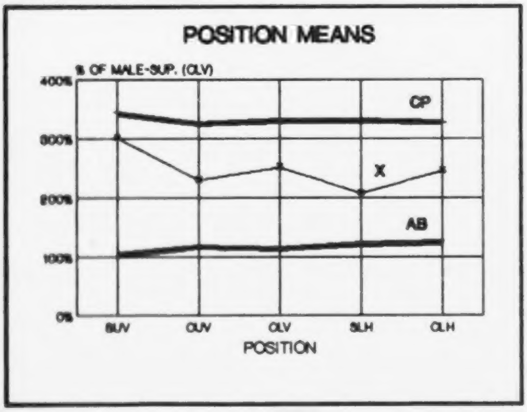

FIGURE 1. Mean performance by position of 32 **CP** subjects and the mean performance of 100 **AB** subjects' inferior hands compared to male superior hand performance in the **CLV** position.

DISCUSSION

The general implications of these findings regarding able-bodied subjects was that gender, hand superiority, and position or direction of movement can significantly affect performance. Each of these factors is not normally considered in task design (1, 2, 6). The effects of Position and Device were also evaluated for a group of individuals with cerebral palsy to determine if there existed patterns of performance variations that could be generalized to this population.

Position Effect

The position averages for the group of individuals with cerebral palsy (CP) were stable across the five positions, Figure 1. There was not a positional superiority indicated by this group for any device tested. This was somewhat surprising given our experience in task modification which indicated that there tended to be a preference for the SLH position by a significant number of subjects. A possible reason for this discrepancy is that the dependent variable in this study is seconds/action or speed and positional preference is based upon perceived ease or difficulty. The difference in selection criteria may produce different task configurations.

Device Effect

There was a significant degree of variability in performance that depended upon the device evaluated, Figure 2. Devices that required more controlled motions (Rotary Detent, Scalloped Hand-Knob, and Balanced Crank) showed a marked decrease in speed compared to able-bodied standards. Some basic design principles that were indicated by these results were that for on/off types of control, push-buttons were superior to toggle switches or rotary detent switches, and that for rotary input a large crank was superior to a hand-knob or balanced crank.

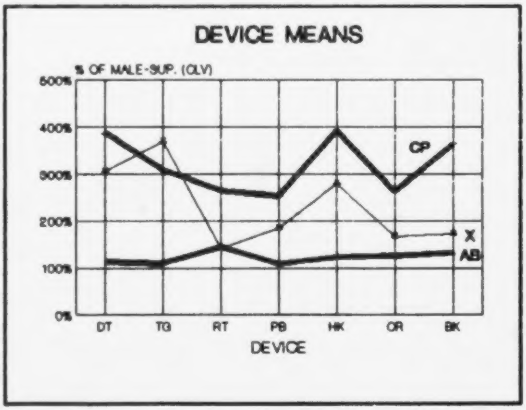

FIGURE 2. Mean performance by device of 32 **CP** subjects and the mean performance of 100 **AB** subjects' inferior hands compared to male superior hand performance in the **CLV** position.

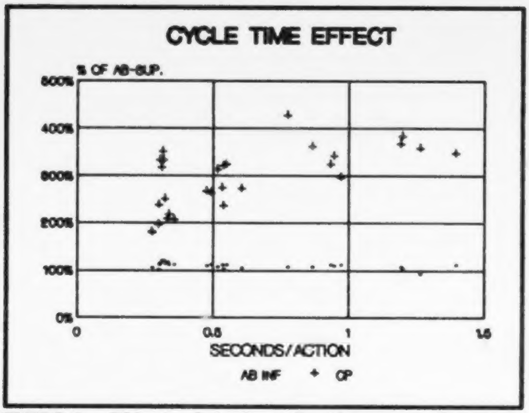

FIGURE 3. Effect of task cycle time upon the mean performance of 32 CP subjects and the mean performance of the inferior hands of 100 AB subjects.

Cycle Time Effect

A commonly held assumption is that a single multiplier may be used to predict the performance of an individual with a disability on a particular task, that is; that a subject will perform at some constant percentage of standard. The average percent of standard was plotted against the standard cycle time of able-bodied superior hands for 28 tasks. Figure 3 shows the mean data for 32 CP subjects and the mean data of 100 AB subjects' inferior hands. The percentage difference between the AB group's superior and inferior hands is constant regardless of the length of time required for the task. The CP group indicates a trend toward a larger multiplier for tasks with a longer cycle time.

Individual Pattern

As an example of the desirability of developing individual specific as opposed to generalized modifications, a specific client's data (X) was plotted in each of the graphs. This idividual demonstrated a unique profile with a significant position effect, Figure 1, and better performance with rotary detent DT than toggle switches TG. The subject's response time RT was nearly the same as able-bodied subjects' inferior hands, Figure 2.

CONCLUSIONS

The performance of the group of individuals with cerebral palsy was similar to that of able-bodied subjects in pattern even though the level of functioning was much lower. This tends to indicate that the same bio-mechanical principles are involved in controlled performance. Significant differences in pattern occurred for tasks requiring significant feedback control (rotary detent, scalloped hand knob, and balanced crank). Their relative level of functioning was as good for push buttons as it was for the large crank. One might think that the large crank would be superior.

The examination of performance compared to the cycle time of the able-bodied standards (Figure 3.) indicates that the use of a constant multiplier for predicting specific task performance may be in error. A possible implication of these findings is that cerebral palsied clients may perform relatively better if their tasks are designed to require a greater number of short cycled elements rather than fewer long cycled elements.

The data from a single subject is not well represented by the group means. Major deviations from group norms were found in both position and device analyses. Effective modifications must consider individual specific characteristics.

ACKNOWLEDGMENTS

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THE TECHNICAL AIDS AND ASSISTANCE FOR DISABLED CENTER: A CONSUMER PROJECT

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ABSTRACT

The Technical Aids and Assistance for Disabled (TAAD) Center, founded by COPH-II (The Committee on Personal Computers and the Handicapped) is a center which provides consumer solutions to problems relating to the access of personal computer technology by persons with disabilities.

The TAAD Center provides services with an emphasis and perspective in the selection and application of microcomputers that is an alternative to the conventional approach of the rehabilitation network. The center's approach allows the end users to make an informed decision as to which system or device best meets their needs. This is accomplished by providing hands-on use with various systems, and by drawing upon consumer experiences, via a computer bulletin board. Other services include a technical aids committee which provides solutions to special problems, collection and dissemination of printed materials, equipment loans, and equipment modifications by volunteers.

Supporting organizations, agencies, and departments supply the initial grant so that all service can be provide free of charge. This helps to further address the needs of a population of severely disabled individuals which is traditionally underserved.

THE FOUNDING ORGANIZATION: A HISTORY

The Committee on Personal Computers and the Handicapped was conceived in 1981 in the Chicago area by five members of the Illinois Congress of Organizations of the Physically Handicapped (COPH). COPH-2 is a volunteer organization governed by persons with disabilities. Their goal has been to assist persons with severe and varying impaiments to access personal computers. By the end of 1984 with no active membership campaign, COPH-2 nevertheless numbered over 600 members nationwide and had a representation of persons with visual, physical, hearing, communication, and learning disabilities.

COPH - 2 's efforts have been recognized by such publications as the *Wall Street Journal* (front page), and *Disabled USA*.

GENERAL PURPOSE OF THE TAAD CENTER

The TAAD Center makes more efficient the process whereby individuals with severe disabilities gain access to personal computers and other technologies which can significantly improve their lives. Better utilization of technologies will increase communication, mobility, and environmental control in educational, vocational, recreational, and social activities. An increase in the numbers of persons served will result from the general purpose of this co-operative project.

SUMMARY OF PROJECT GOALS AND OBJECTIVES

The consumer-run TAAD Center is situated in a public setting, provides (1) a wide range of materials; (2) hands-on trial use of technical aids; (3) peer counseling; (4) consumer networking; and (5) technical advice and assistance. The center plan intends to set-up initially a center dealing with personal computers and related technology.

There have been in existence projects of a similar nature, however, the essential difference is that of consumer networking which can provide an abundance of valuable information that will then be directed to others. Other innovations of this project include consumer management, a public setting, hours that correspond to client needs, and service provided on a non-fee basis.

PLAN OF SERVICE

Services will be conveniently available on a daily basis at no charge to persons with disability, their friends and advocates and members of the rehabilitation network. These services will consist of but not be limited to: (a) giving free technical advice, (b) arranging for free loans of computers and computer adaptive devices, (c) sponsoring public meetings for purposes of problen solving and equipment demonstrations, (d) disseminating information kits and publications, (e) networking persons with common concerns, (f) providing demonstrations and hands-on use of computer technologies, and (g) providing peer counselling.

Advocacy before manufacturers, distributors, public policy makers, and rehabilitation and other provider groups will be a pivotal activity of this project. Also project concerns and philosophy will be expressed in the public media, and in academic, technical, and scientific forums.

The initial goals and objectives include augmenting the initial contract services of Illinois government.

DIRECTION OF TAAD CENTER

During the next several years, the center will be directed towards utilizing the already existing COPH-2 computer bulletin board on a local and national basis. This bulletin board will be used for the daily compilation and dissemination of technical information via a consumer network.

Also, the project support will be expanded by soliciting both material and financial resources from private and other public sectors. In order to enable disabled persons to obtain maximum benefit from their technical aids, a reservoir of volunteers and service personnel (paid and unpaid) will be gathered together to establish an additional service component. These services will include the design, fabrication, installation, maintenance, and repair of equipment as well as modification of home and work sites.

Finally, community consultant groups will be formed to keep the project oriented towards established goals and objectives.

BUDGETING INFORMATION

A initial grant has been provided by three departments of Illinois government: Department of Rehabilitation Services (DORS), The Governor's Planning Council on Developmental Disabilities, and the Department of Mental Health. Efforts are being put forth to solicite the support of many public and private agencies and departments to help the center carry on its efforts on behalf of persons with severe diabilities.

The site is provided through DORS at the Illinois Children's School and Rehabilitation Center, located at 1950 W. Roosevelt Rd. Among other advatages, this location helps to provide physically disabled children in the school with exposure to adults having similar disablities.

MICROCOMPUTER EQUIPMENT NEEDS

The Center has aquired a number of microcomputer systems in order to meet the goals of the project, serving as the demonstration and office equipment for the TAAD Center. Additional machines will be aquired for use as loan equipment for trial use in home and work settings. The following list is representative of the types of equipment implemented in the initial phase of the project.

COMPUTERS:
2 Apple //e systems
1 Apple //c or an additional Apple //e (for office use)
1 Apple //gs
2 Macintosh Pluses
2 MS-DOS machines (with serial ports)
Several low-cost machines : Tandy Model 100, Tandy CoCo 2,
Commodore 128

PERIPHERALS:
3 dot-matrix printers
1-2 sheet feeders
3 modems
2-3 hard disk drives
several 3-1/2" floppy drives
several 5-1/4" floppy drives
monitors
demonstration software, for such major applications as WP, spreadsheet, database, page-layout, telecommunications, games, etc.

The TAAD Center plans to augment this demonstration equipment with additional machines (as funding and equipment grants allow) in order to provide longer-term free loans of systems for evaluation in the work and home environments.

ADAPTIVE EQUIPMENT

The TAAD Center has aquired and will continue to aquire a wide selection of adaptive equipment, in order to demonstrate representative examples of each type of device on the major personal computer systems. The Center also features unique combinations of equipment (such as the Headmaster and Macintosh) in cases where it provides exceptional capabilities or price/performance advantages.

A major factor in the selection of adaptive devices is the availability through established, reputable manufacturers, whose stability ensures the continued service and availability of the device. Another key factor is the reputation of a particular device in providing productive, independent use of the personal computer or peripherals. Some examples of equipment meeting these criteria include the Adaptive Firmware card and products by the Prentke Romich Company. Also, a number of low cost adaptations to inexpensive microcomputers will be displayed as an alternative option to meet the needs of the consumer.

THE BULLETIN BOARD

The bulletin board committee interviews and compiles information from interview, and document their experiences with technology for reapplication as solutions to the problems of others. The bulletin board provides a medium for matching individual users for in-depth question and answer sessions, providing networking for consumers across the country. The bulletin board also serves as an electronic newsletter, linking individuals throughout the nation, and publicly displaying solutions.

In addition to its other duties, The Technical Aids Committee will serve as a moderator in relating previous experiences with computers in the context of newer, more advanced equipment. For instance, past experience with floppy disk drives is usually limited to the 5-1/4" format. However, the higher capacity of the 3-1/2" disk drives will serve to greatly reduce the frequency of diskette swapping, and to greatly simplify this task as well (perhaps eliminating the need for a diskette manipulation aid). Another example is the use of extended RAM, which can increase productivity, improve system response, and eliminate the need for additional adaptive equipment.

The advancement of personal computers has provided increased access and usability to the general public; it has done so even more dramatically for the disabled. Disabled persons were among the first "end users" to embrace microcomputer technology, and they can benefit greatly by remaining current with advancements, whether developed for the general public, or by manufacturers who are sensitive to the needs of the disabled.

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Service Delivery in a Dependency Reduction Program

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ABSTRACT

As a result of California Assembly Bill 1813, a Dependency Reduction Project (DRP) was established to help severely disabled individuals obtain assistive devices that are custom tailored to meet their needs. The program provided assistance in two ways: first, through the design and fabrication of custom equipment and second, through loan guarantee provision to help individuals purchase equipment. Two centers, the Assistive Device Center at California State University, Sacramento and Project Threshold with the Rancho Rehabilitation Engineering Center, Downey, were awarded contracts by the Department of Rehabilitation to operate this program. This paper discusses the service delivery process developed by the two centers and includes case studies.

INTRODUCTION

Even though a large number of commercially available assistive devices exist, many individuals with severe disabilities are unable to obtain appropriate equipment because they lack funding and/or "off-the-shelf" equipment does not meet their needs.

In passing AB 1813, the California State legislature recognized two major needs relating to the provision of durable equipment, adaptive aids and assistive devices to individuals with disabilities. First, the legislature noted there was a need for a loan guarantee program to assist employers and employees with disabilities to purchase the aforementioned equipment in order to engage in supported employment.

Second, the legislature recognized the need for persons with disabilities to obtain appropriate, individually tailored systems to allow them to communicate and function more independently within the community. By passing AB 1813, the legislature approved funding for two Dependency Reduction Projects to function as pilot centers for developing the necessary delivery system to allow disabled individuals to obtain these customized systems. These Centers were: The Assistive Device Center (ADC) at California State University, Sacramento and Project Threshold at the Rancho Los Amigos Rehabilitation Engineering Center.

The focus of this paper is to describe the Dependency Reduction Program (DRP) in terms of the procedures established and clients seen, and to discuss accomplishments and problems encountered during the initial six months of the project.

ESTABLISHING THE DRP

Project Goals

The goal of the ADC and Rancho Los Amigos was to establish client assessment procedures and relate them to the need for individually tailored systems, provide the design and fabrication of these systems and provide long term follow-up to insure effectiveness of the provided systems. The need for training and continued involvement with the clients was recognized as essential to long term success. Emphasis was also placed on replication of individually tailored systems for other client's with similar needs.

Project Eligibility

The DRP services were available to persons of any age who were disabled and unable to receive the services from other sources. Specifically, the clients met the following criteria:

* Had a documented disability
* Were ineligible for services from Dept. of Rehabilitation
* Had an identified problem or goal
* Had a need for custom tailored equipment

Structure of the DRP

The system was organized in this fashion: the client service unit accepted applications from potential clients; insured the existence of a medical disability certified by a licensed physician; determined eligibility for funding from existing sources (including, but not restricted to Medi-Cal (Medicaid) and the Department of Rehabilitation); carried out an assessment of client needs and skills; translated the results of this assessment into specifications for durable equipment, adaptive aids or assistive devices; identified, if possible, commercial products which met these specifications, or, if none were available, determined client eligibility for the program and referred him/her to the rehabilitation engineering unit for fitting, training and follow-up services.

To track project activities, including costs, client profiles, services providers, etc., a database using dBaseII was designed specifically for this project. The menu-driven system is configured to provide comprehensive client information for the DRPs to provide service to their clients and report to funding sources. Client information may be added, edited, searched and totaled to provide a wide range of information. Reports may be automatically generated to reflect particular profiles of disabilities, geographic distribution of clients, types of needs served, etc.

Uniform in-take and needs analysis procedures were also developed to deal with clients referred to the program. In general, the assessment procedures were those routinely carried out by the two Centers.

An essential aspect of the DRP is the existence of a comprehensive rehabilitation engineering component. This activity includes the capability to define equipment specifications based on client needs and skills, determine if commercially available devices meet these needs in whole or part, design individually tailored systems, fabricate and test the custom system and then carry out necessary fitting and insure delivery to the client. The rehabilitation engineering activities also include development of user manuals and provision of detailed plans, blueprints and models which are developed. Long term follow-up to insure that maintenance and repair of the provided equipment is available for the life of the equipment. In establishing this capability, both Centers took advantage of existing rehabilitation engineering capabilities. Specific documentation procedures and formats were also adopted to insure consistence and replication of the results.

Publicizing the Program

To make potential consumers of the DRP services aware of the program, a flyer was developed which described the program and referral method to professionals in speech pathology, occupational therapy, physical therapy, special education, and service providers throughout California. Over 3,700 flyers were mailed out in October, 1987. In addition all chapters of the Arthritis Foundation, the California Association of the Physically Handicapped, California Independent Living Associations, Easter Seal Society, Multiple Sclerosis Society, and United Cerebral Palsy Association received flyers. Newspaper articles and announcements in various publications serving disabled persons in California discussed the program.

CLIENT ACTIVITIES

This section describes clients who have been evaluated as potential DRP participants for both sites. In-take to these programs was by both direct inquiry and through the normal client service delivery programs of both centers. All clients seen in the regular client service programs were considered for the DRP if a custom system was a part of the recommendations.

Client Contacts

During the first seven months of the program, over 25 clients seen in our client service programs were considered for the DRP. In addition, telephone or letter inquiries specifically related to the DRP were received from an additional twenty-five persons.

Disposition of Client Referrals

Of the clients seen or referred, many had other sources of funding and did not meet the requirement needs of the DRP. Eight did not seem to represent appropriate referrals to either program. Ten clients, in the assessment phase, are still under consideration but some are awaiting action on applications for other funding sources. The remainder were not considered further for the DRP because they did not require custom systems.

Case Studies

A 29-year old male with Cerebral Palsy who needed assistance in using computer-aided graphics, was referred to the project. He was deemed an appropriate referral since two denials were received from United Cerebral Palsy in Oakland and the Department of Rehabilitation.

The assessment process was initiated and it was found that the client needed to use computer aided design (CAD) software in his work. He was able to access the Trackball using the left lateral surface of his jaw while simultaneously observing the computer screen. The control buttons on the trackball device were tongue-activated. The Assistive Device Center designed a Trackball mounting bracket to allow the client to manipulate the CAD software. The solution consisted of a stainless steel bar bent at 90 degrees and affixed to the table top with a custom-designed screw clamp. The Trackball is attached via an adjustable ball and socket fixture which allows for infinite positioning. The completed system provides a wide latitude of adjustment while being very stable when clamped in place. The device was designed and delivered to the client, who is successfully using it. This custom design involved $129 of design costs, $50 in materials and $200 of fabrication costs.

A 33-year old female with Cerebral Palsy-spastic quadriplegia who needed assistance with mounting a Zygo ScanWriter, was referred to Project Threshold. Since denials for funding were received from a Regional Center and Medi-Cal, she was referred to this program.

The assessment indicated the client had difficulty using her communication equipment because of a foot switch mounting which was in disrepair. Four changes to her equipment were required to correct the problem: 1) to permanently affix the ScanWriter mounting platform and arm to the wheelchair armrest to insure stability and to allow the platform to swing out to the side. 2) to stabilize the foot switch housing to allow foot control of the communication device while withstanding impact received during use. 3) to mount the ScanWriter battery to the back of the wheelchair. 4) to create a mounting bracket for the speech synthesizer used with the ScanWriter. All of the above work was completed and the estimate of providing these services was $325.00. This work involved custom modification to existing commercial equipment, with the actual cost being $250.00 and the cost of the evaluation being $107.50.

PROGRESS MADE IN IMPLEMENTING THE DRP

Problems in Meeting the Original Time Lines of the DRP

One area of concern was found in relation to successful implementation of the DRP: adherence to specified time lines. Because the implementation of this program required that funding decisions be made by agencies outside of the two Centers, time frames set by the Department of Rehabilitation were barely achievable. In our experience, it typically takes more than 10 working days after first client contact for a funding source to decide on paying for an assessment and issue the required authorization forms (e.g. a Treatment Authorization Request-TAR). These delays are out of the control of the service provider, but this step must be completed before the assessment and implementation process can begin.

The 30 working day specification from initial contact to client recommendations was also affected by these considerations. Client reports containing assessment results and system recommendations were available within 30 working days of the client assessment. However, due to the concerns outlined above, it cannot be guaranteed that this was also 30 days from first contact with the applicant.

Operational Problems

The major challenges faced in implementing this program were in the areas of eligibility for service and scope of the project. The project clearly specified that custom equipment was to be provided. Because of funding cutbacks in other projects, many individuals contacted the DRPs to fund commercially available devices. This was clearly outside of the project's scope. In addition, the DRP was intended to provide the custom components of the systems only, and the cost of modifying commercial devices was the responsibility of other sources. This factor limited the program's effectiveness since many individuals could not afford the cost of the device to be modified, even if the modification was provided by the DRP. Because the program was administered by the Department of Rehabilitation, it was often erroneously assumed that vocational eligibility was required under the DRP. This was not the case, and clients of all ages were considered. The original enabling legislation provided for the program to sunset in June, 1987 unless extended by the legislature. The Department of Rehabilitation decided in February, 1987 after seven months of program operation not to seek extension of the program. This time frame was too short to demonstrate effectiveness of need. For example, many of the newsletters and other sources of publicity were not published until after this date, and the number of referrals and inquiries has increased substantially since that time. Efforts are currently underway to extend this program for another year.

SUMMARY

The Dependency Reduction Projects represent an attempt by the California state legislature to recognize the needs of disabled individual to obtain custom or individually tailored devices at costs comparable to those of commercial devices. Several clients have been served by this program, and more are in various phases of completion. Valuable information has been accumulated regarding the needs for custom systems and the requirements for such a delivery system. Operational procedures established will be of benefit to others interested in providing custom or individually tailored assistive devices to disabled clients.

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POWERED HEIGHT ADJUSTMENT FOR A LECTERN AND FILING CABINET TO BE USED BY AN EMPLOYEE IN A WHEELCHAIR

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ABSTRACT

Simple elevation restrictions which result in accessibility problems for employees in wheelchairs are apparent in every aspect of life. Two specific problems are addressed in this paper. The first involves height adjustment of a lectern. It was desired that the lectern be adjustable in height from 30" to 44", allowing either a speaker in a wheelchair or an ambulatory person to use it. Commercially available lecterns with height adjustments only allow for 6" of height differential, which is far below the required 14". The solution was simple and significantly less expensive than the inadequate commercially available models. The second problem addressed is a filing cabinet which needed to be made accessible to an employment specialist in a wheelchair. The final product needed to have the capacity of a standard 4-drawer filing cabinet, had to be lockable for security purposes, and needed to be fireproof. Commercially available models were either fireproof or adjustable but not both, and very expensive. The solution met all the requirements and was significantly less costly.

ADJUSTABLE LECTERN

PROBLEM DEFINITION

Center Industries Corporation (CIC) in Wichita, Kansas is a competitive industry that employs at least 75% physically disabled persons, and as a result, several of their employees are in wheelchairs and face accessibility problems. One such accessibility problem was faced by an office manager who is in a wheelchair and who has to give presentations on occasions in CIC's audio-visual room. In order to make these presentations she requires a lectern, or speaker stand, that is low enough to be wheelchair accessible. The lectern also needs to be usable by a standing able-bodied employee.

Measurements were taken and it was found that the lowest height required was 30" and the greatest height 44", for an adjustable range of 14". Enquiries were made to several of the office supply houses in the Wichita area regarding adjustable lecterns. A few lecterns with adjustment capabilities were found, but only with an adjustment range of 6". The prices of these available lecterns ranged from $1800.00 to $2500.00, depending on extras. Unfortunately, their designs were not intended for wheelchair use but instead for adjustment based only on one's standing height.

PROBLEM SOLUTION

The solution was for CIC to have their own lectern built according to the required specifications. Those specifications included: (1) 14" of adjustable height range from 30" to 44", (2) an overhang that would accomodate the feet and legs of clients in wheelchairs, (3) switches for up and down motion within reach of someone in a wheelchair, (4) travel of complete range up or down within reasonable amount of time, and (5) lectern to be a self-contained, standalone unit.

In order to accomplish the above, an upper cabinet was made to slip down over a bottom stand. The bottom stand was faced with a plastic laminate on the outside and the upper cabinet was lined with strips of teflon on the inside. Thus the teflon acted as a bearing surface between the upper cabinet and bottom stand and made for smooth up and down action. The up and down action was accomplished by using an acme-screw driven by belt and sheave from a reversible motor. The switches for up and down motion were mounted on the side to allow for good accessibility, and limit switches placed inside the cabinet were used to shut off power when the bottom or top limits had been reached. The motor/belt-sheave/screw combination were used instead of a linear actuator because of the speed of travel required. The resulting lectern stands alone and requires only to be plugged in to 110-volt power.

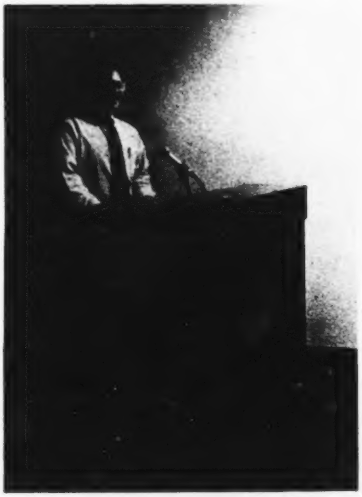

Figure 1. Ambulatory person using lectern.

COSTS

The lectern was contracted to an outside fabricator for the sum of $800.00. This was significantly less than the inadequate commercially available models.

Figure 2. Lectern lowered for use by someone in a wheelchair.

RESULTS/DISCUSSION

The result is a custom-made oak lectern that looks like a commercial model. It has been in use for approximately 9 months and has accomodated CIC's office manager on several occasions. Figure 1 shows the lectern being used by an ambulatory person, and in figure 2 the lectern has been lowered for use by someone in a wheelchair.

If a linear actuator could be found that would give 14" of travel in less than or equal to 8 seconds and be purchased at a price of $250.00 or less, it would be preferred over the motor/pulley/screw combination. This would be for two reasons: (1) the linear actuator would make for easier fabrication, and (2) the linear actuator probably would be quieter than the existing solution.

ADJUSTABLE FILING CABINET

PROBLEM DEFINITION

Another such elevation problem was encountered at CIC. This time the problem involved a filing cabinet which needed to be made accessible to an employment specialist in a wheelchair. The employee has very limited reach and limited strength making the use of a normal filing cabinet almost impossible. Several factors had to be taken into consideration in looking for a solution: (1) the filing cabinet needed to have the capacity of a standard 4-drawer filing cabinet, (2) it needed to be lockable for security purposes, (3) it needed to be fireproof and (4) it needed to be accessible to someone in a wheelchair.

Again enquiries were made to several of the office supply houses in the Wichita area, this time concerning adjustable filing cabinets. The search turned up a few motorized cabinets that were adjustable but not fireproof, and those fireproof cabinets that were found were not adjustable. Prices ranged anywhere from $2500.00 to $10000.00 depending on the size.

PROBLEM SOLUTION

Engineers at the Daniel M. Carney Rehabilitation Engineering Center in Wichita were called by CIC to assist in the design of a suitable filing cabinet. The result was a filing cabinet that met all of the above criteria. The design used a linear actuator connected to chains that ran over sprockets and lifted a cabinet up and down. The cabinet itself was designed to handle the same linear inches of files as a standard 4-drawer filing cabinet. One accessible opening in front allowed for doors to be opened and closed by employee, and lockable. Limit switches were positioned inside cabinet to stop up or down motion in appropriate locations. And 1" thick ceramic fiber insulation along with #10 gauge steel outer skin assured safety of files against fire. The design was fabricated at the Carney Center by engineers and technicians.

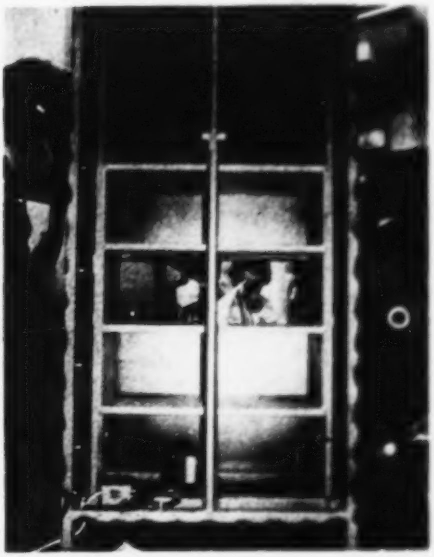

Figure 3. Rear view showing internal works.

COSTS

Material costs for the project were approximately $900.00. Labor was provided by the Carney Rehabilitation Engineering Center.

RESULTS/DISCUSSION

Figure 3 shows a rear view of the overall cabinet and its internal workings. Figure 4 is a side view showing the limit switches in place and the accompanying wiring. Figure 5 is a rear view again with the internal cabinet removed, showing the 1" thick insulation held in place by studs. And finally figure 6 shows the finished product being used by the employee at CIC.

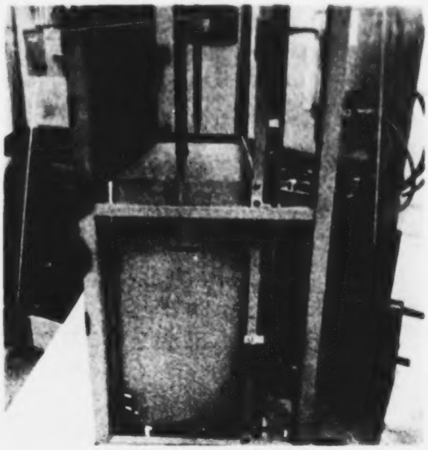

Figure 4. Side view showing limit switches.

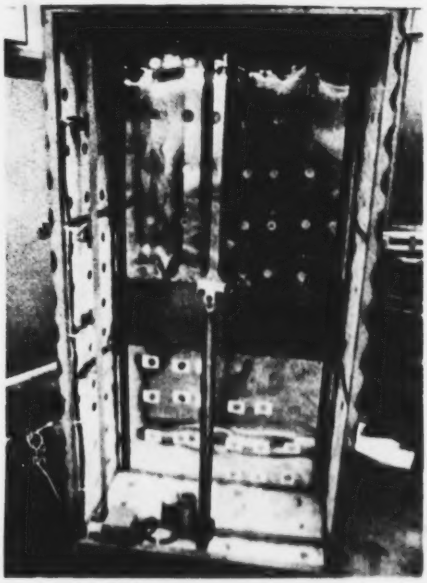

Figure 5. Rear view showing insulation.

Additional helpful "funnels" were made out of aluminum sheet to help the employee retrieve and return files. As of the writing of this paper the cabinet had been in use for approximately 3 months and was making it possible for the employee to perform an otherwise impossible task.

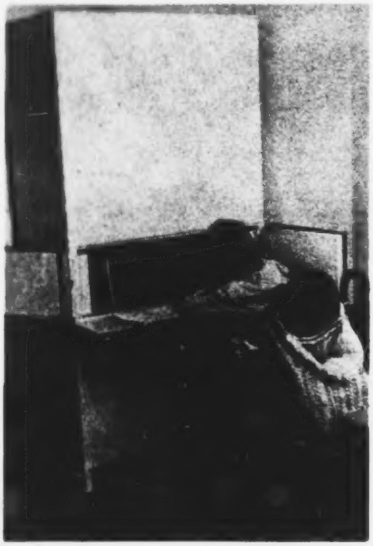

Figure 6. The finished cabinet in use.

If anyone reading this article would desire more information feel free to contact:

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RTT: A MODEL FOR TECHNOLOGICAL APPLICATIONS

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ABSTRACT - This paper is a step-by-step description of an effective technology based evaluation and training process, used at CAST Resources. An illustrative case study of a child is used to describe the process. This child entered the center with severe communication and mobility impairments, along with no efficient means of cognitive learning.

The enormous power of advanced technology is rapidly expanding the capabilities of scientists, business people, professionals and students. Unfortunately, the potential that advanced technology holds for people who suffer special handicaps is largely untapped. Though powerful technological tools are available which could assist disabled individuals to function more independently, there are limited resources which provide ongoing evaluation, training, and service coordination in the use of applicable technologies.

Finding a single agency to serve the total needs of the handicapped population has traditionally been a major problem. For example, a quadriplegic in need of an electric wheelchair, communication device, computer access and environmental controls is often followed by many different clinics. Such a model provides isolated solutions to an individual's multiple needs, resulting in unnecessary large quantities of adaptive equipment with multiple input devices, and no coordination of treatment, training and follow-up.

The Rehabilitation Technology Laboratory (RTL) of the Center for Applied Special Technology (CAST) was founded to ensure that the benefits of advanced technologies are appropriately provided to handicapped individuals for the purpose of optimizing their independent functioning. At the RTL we have developed a Rehabilitation Technology Team (RTT).
This multidisciplinary team specializes in assessment, training and follow-up of handicapped individuals and is trained to serve individuals with varying types of handicapping condition. Areas of specific specialized services include: seating and positioning, mobility, augmentative communication, environmental controls, active stimulation, computer adaptations for mobility-limited individuals, and work site and home modifications.

The Rehabilitation Technology Team includes a physical therapist, occupational therapist, speech and language pathologist, neuropsychologist, rehabilitation engineer, medical equipment vendor, social service consultant, and software specialists in the fields of language and cognitive development. Members of the RTT serve clients in the following major ways:

- determining whether technological equipment is available that could enhance their capacities for learning and independent living;

-adapting or designing technological equipment to meet individual needs;

-evaluating their physical and mental capacities for using computer equipment;

-training clients and their careproviders in the use of adaptive equipment.

-streamlining adaptive equipment and their input mechanisms. ie: (one switch operates all systems)

Anyone within the community setting is able to refer a client to the RTL for technological services ie: (physician, teacher, parent, guardian, therapist, agency, self, friend etc.).

Three years ago, we met a passive and depressed five year old boy, with a severe hearing loss who was unable to control any part of his body except his feet. He used his feet to answer "yes" and "no" questions, but had no other effective way to communicate. He could not learn about the world by asking questions, or present his ideas to others. To move in his environment, he depended on an adult to push his wheelchair. He was unable to actively play with his two younger siblings, or his family friends. Billy is from a rural community, and had been receiving a variety of fragmented services from clinics at the nearest city hospital, 50 miles from his home.

Billy was scheduled for an evaluation with the RTT. Within moments of his first visit, Billy demonstrated the ability to operate an electric wheelchair by manipulating a joystick with his left foot. He immediately drove the wheelchair up to a computer, and began to operate it with his left foot in a single switch scan mode. Through his use of the computer we discovered that Billy was able to match letters, begin to identify some letters, count, and choose pictures that represented ideas he wanted to express. This was the first time Billy was able to actively affect his environment: the change in his demeanor was remarkable. This formerly passive and depressed boy now began to show his personality.

As a result of Billy's initial evaluation, the RTT recommended that he receive:

1) an electric wheelchair he can use to move about his environment on his own.

2) a portable electronic communication system allowing him to communicate ideas, ask questions and express his basic needs at home, in school, and within the community.

3) a computer with switches allowing him to operate the computer on his own both at school and home,

4) educational software to develop his reading, writing, language and math skills.

5) a portable electronic feeder to allow Billy independence during meal times in a variety of settings.

During a series of initial follow-up training sessions, Billy learned to use a power wheelchair and explored a variety of communication devices to find the one most effective for use at school and home. Currently, he is continuing to use new software as his academic skills improve. An electronic feeder was tried with great success, with Billy activating the system with his foot using a dual activated switch control.

Training sessions have been done at the Laboratory, as well as within Billy's academic environment. Many team meetings and consultation services have been provided to both the school staff and family regarding all of the technological aids that Billy is using.

Billy's Team Manager from the RTT met with persons from Billy's school and town to discuss recommendations and help research funding sources. (Funding seems to be the major area of difficulty for many handicapped people.) As a result of the meeting, the town has agreed to provide Billy with the recommended computer, ACS ScanPac augmentative communication device (joy stick activated), switches, and software. A local community group in Billies home town has helped supplement the cost of the academic related equipment that the town agreed to purchase for Billy. We continue to remain involved with Billy, communicating with his Special Education Director in his home town, as well as the coordinator at his school, regarding the ordering of more equipment and/or continuation of training services as needed.

Billy has obtained a Fortress Wheelchair with a special mounting plate, that enables him to use his Safety Travel Chair (STC) for positioning and as a back up wheelchair when his Fortress is down for service. Billy's joy stick is mounted on the foot plate of the STC. He is very accurate with his driving skills at home, school, and in the community.

Today, Billy is independent in mobility and is able to carry on a conversation at all times while in his wheelchair. He is learning as well as expressing his needs and wants. Billy has gained access to his world through one 5 position joy stick. His ACS ScanPac is connected to a Fortress 5 switch interface junction box that is connected to his Fortress commander module along with his joystick. This interface allows Billy to drive, speak, learn, and control his environment with the same joystick control. The ScanPac through remote control is able to access his Apple IIe computer system with Adaptive Firmware Card for academic learning. Through the use of technology, Billy has become more independent, and learning has become exciting and rewarding for Billy. Some of the software programs he is using are:

-Scuffy and Friends by Hartley;
-Sticky Bear Math 1 by Xerox Weekly Reader Family Software;
-Magic Spells by Learning Company;
-Site Word Spelling by Handicapped Children Computer Cooperative;
-Magic Slate by Sunburst.

It is our hope that he will be able to enter the mainstream within his home town educational system in the near future with the aid of his technology.

Billy's system is streamlined and efficient. Throughout the evaluation and training sessions with the RTT, Billy has been assessed and provided with solutions for:

- positioning and seating
- power mobility
- augmentative communication
- environmental controls
- adaptive computer access
- appropriate educational software
- independent feeding

using **ONE** activation control for all of his systems, a joystick.
Equipment recommendations have been made by the whole team, with involvement of the family and school personnel.

Persons with multiple handicaps appear best served by an interdisciplinary team such as CAST'S Rehabilitation Technology Team. Each discipline can provide a different service , and all services can be integrated as part of an ongoing evaluation, training, and reevaluation process. In this way the complex and frequently changing needs of handicapped individuals can be met in a single agency.

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A STRUCTURAL AND FUNCTIONAL ANALYSIS OF REHABILITATION DELIVERY SYSTEMS

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ABSTRACT

Current rehabilitation delivery systems appear to involve four somewhat related components: 1) deficits analysis, 2) instrumentation/augmentation, 3) tool-user matching and, 4) skill training. For the delivery of rehabilitation treatment the four components have emerged within multi- or inter-disciplinary service approaches. The weaknesses of the approaches are discussed regarding natural environment requirements. Finally, behavior analytic services are reviewed and proposed for inclusion on the rehabilitation team as having special skills to facilitate instrumentation, tool-user matching, and skill development components under a transdisciplinary model.

SERVICE PROBLEM

Post acute rehabilitation services occur in the context of an overarching model or structure of service delivery. The two most common service delivery structures are multidisciplinary (MDT) and interdisciplinary (IDT) team models. The multidisciplinary approach to delivery of rehabilitation services relies on the expertise of several professionals who work with the client on an individual basis. Thus, no formal attempt is made to allocate resources or set priorities for client needs as they overlap across disciplines (1).

Interdisciplinary models of rehabilitation services are somewhat different than MDT in that, formal channels of communication are established and a case manager is assigned to coordinate services. Treatment decisions are made by group consensus. However, assessment and implementation of treatment is conducted by each discipline. The problem with both the MDT and IDT models for rehabilitation is that such services are provided in isolation of the natural context in which the criterion skills being trained are to occur (2).

As a result, the goals and provision of treatment based on the MDT and IDT models are structural rather than the functional with respect to the needs of the client. This can be seen in several ways (1) client competence is not assessed in the natural environment where performance is expected to occur, (2) assessments may focus on isolated skills instead of skills clusters that are crucial to successful adjustment and community living, (3) assessments frequently result in diagnostic labels with minimal information regarding pragmatic approaches to remediating skill deficits, (4) when professionals work in isolation it is difficult to collaborate on performance of clients in natural situations and, (5) because of limited staff and time, clients may receive small amounts of treatment.

PROPOSED RESOLUTION

In contrast is the transdisciplinary model (TDT) of service delivery. The TDT model is functional in provision of services by transferring information and implementation of rehabilitation services to other professionals and paraprofessionals working with the client in the natural environment, e.g., at home. Thus, the TDT model strives to take into account items 1-5 mentioned above. Most importantly, the TDT model is sensitive to the context in which assessment, training and performance of skills occur.

The assessment of client performance in the natural environment should, ideally, be done by each discipline represented on the rehabilitation team. Rehabilitation service teams frequently include speech and language therapy, physical and occupational therapy, rehabilitation engineers, medicine and psychology. Characteristically the natural environment assessments are provided by occupational therapy, rehabilitation engineers and sometimes by speech and language personnel. Physical therapy and medicine often provide specialized services relating to physical status such as range of motion or limb condition, etc. More traditional psychological services yield information regarding emotional and neuropsychological status, i.e., describing the structure of personality, intellectual functioning level, and neuropsychological considerations with relatively few pragmatic applications to rehabilitation.

Recent innovations and applications of behavior analysis to rehabilitation of persons with closed-head injuries (3, 4, 5, 6) comatose patients (7) and persons with spinal cord injuries (8) indicates the importance of a behavior analytic approach to overall treatment goals. An important component of behavior analytic services is commitment to assessment and treatment in the natural environment and, thus the approach is functional in nature.

BEHAVIOR ANALYSIS

A behavioral or functional approach to

rehabilitation is based on an analysis of the context within which behaviors are performed, measurement of directly observable behavior and the consequences which follow performance of behavior. Like other efforts towards rehabilitation, a behavioral approach focuses on teaching new skills. Behavior analytic rehabilitation is based on seven principles, each of which will be briefly described. (1) Environmental analysis points out the pragmatic approach to rehabilitation by analyzing the critical behaviors needed to be successful in the community and the context within which they occur. Rearrangement of the environment, e.g., positioning of materials, addition of salient cues for performance, are also components of this step. (2) Task analysis is a method of breaking large behavioral competencies e.g., "operate motorized wheelchair", into smaller steps or responses, such as "grab joystick". The chain of responses, when pieced together, constitutes the larger behavioral competency. Training of the constituent components can then occur in several ways. A task analysis also describes the conditions or stimulus aspects under which a behavior should occur, thus ensuring training of the skills in the correct context. (3) Instruction refers to the sequencing of training trials. Training trials can be massed where one step is repeatedly practiced and trained to criterion prior to training on the next response in the sequence. An alternative is distributed trials where a sequence of steps is practiced, however the opportunity to practice a specific step does not occur until all the steps in the task have been practiced, e.g., grab the joystick is practiced after all the other steps required to operate the wheelchair have been performed. (4) Prompting simply means providing as much assistance to the client as necessary to ensure correct performance of the behavior. Prompting consists of verbal instruction, demonstration, partial assistance and full assistance. Other types of prompts are also important to the performance of skills such as color coding of dials and picture prompts used to cue task performance or sequencing. (5) Reinforcement is the keystone upon which all skills are built. Reinforcement is simply a positive consequence that follows the occurrence of the new skill being learned and will increase the likelihood of its occurrence. Behavior analysts are trained to assess and specify critical reinforcement parameters for teaching skills in the natural environment. (6) Generalization of skills refers to the performance of behaviors in the variety of contexts where they naturally occur. Generalized performance of skills can be achieved through training (a) in each situation in which the behavior is to occur, (b) using multiple examples of situations, and (c) use of a range of examples which teach the "general case". (7) Maintenance and adherence refer to continued performance of skills or adherence to treatment regimens. A breakdown in performance may be a function of stimulus or consequent variables. For example, poor stimulus control may be due to ineffective or inefficient training or an unplanned change in stimulus conditions which control the occurrence of the behavior. Lack of maintenance of skills may also be due to ineffective reinforcement of correct (desired) performance and/or more powerful reinforcement for alternative ways of performing. Complexity of treatment regimens is also a critical factor when evaluating a breakdown in maintenance of skills.

CONCLUSION

As can be seen a behavior analytic approach can be used to assist treatment by many professionals on the rehabilitation team. The approach is transdisciplinary in that stress is placed on patient performance of criterion skills which are evaluated and trained in the natural environment. Rehabilitation services could be enhanced by the use of a transdisciplinary model which takes into consideration the dynamic interaction between persons and environment and encorporating behavioral analysts on the rehabilitation team.

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IMPLEMENTING A SERVICE DELIVERY PROGRAM: EXPERIENCES IN PENNSYLVANIA

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ABSTRACT

The inherent difficulties of delivering high-cost, technologically complex rehabilitation engineering products to a widely dispersed population are well known. In Pennsylvania the Department of Special Education, Bureau of Special Education has developed an innovative program to provide high technology adaptations for physically handicapped, educationally disadvantaged students. Now in operation for over two years, the Pennsylvania Special Education Assistive Device Center presents a service delivery model which is uniquely suited to take advantage of current market and funding opportunities.

This presentation will outline the funding structure, staffing and program operation plan. Funding is provided through P.L. 94-142 monies, which are available in every state. The multidisciplinary staff of the center includes a speech pathologist, educational technologist, occupational therapist, rehabilitation engineer, coordinator and support staff. In addition, training of local personnel (Local Augmentative Specialists) supports the daily use and needs identification of individual students. Both a long and short-term loan program have placed over 300 complete device systems with individual students for home and school use.

INTRODUCTION

In the poster session at this conference, results from the field on the efficacy of commercially available devices with preschool, elementary and secondary students will be presented. Tutorial materials developed by the project to train educators in the selection and application of assistive devices will be shown. Summary results of a national conference held this April which brought together state-level education agency representatives will be discussed. The focus of this conference was on examining existing models and identifying strategies for the application of rehabilitation engineering products in schools.

The ability of this program to forge close cooperative relationships with manufacturers and developers of assistive devices is highlighted in another presentation by the project's rehabilitation engineer.

In the special ed technology universe inhabited by teachers, therapists, rehabilition engineers, computer experts, administrators, parents and students even the term "assistive devices" is open to debate. It was recently defined in the Encyclopedia of Special Education:

> *The term assistive device has been applied to a wide range of highly specialized mechanical, electronic, and computer-based tools which are now commonly used in rehabilitation and special education settings. The assistive device is typically designed to perform a particular prosthetic or orthotic function, but it is not a prosthesis nor an orthosis in the traditional medical sense. (Reynolds & Mann, 1987).*

This functional definition goes on to include sensory aids, communication aids, computer access devices, and aids to daily living. Writing aids and special-function or adapted learning tools such as a specially-mounted commercial device, for example, a calculator or cassette tape recorder with sliding control to ease operation, are also considered assistive or adaptive devices. The term "assistive devices" is preferable, because it relates to the function of the article, rather than to its' derivation. Such devices may in fact be commercially available special function items, adapted from mass market items, or a combination of both (BG: Rodgers, 1984). Most assistive device systems contain components of each, such as the typical Apple computer set-up, with an adapted keyboard, and a customized switch or headpointer.

Educators are not the only professionals currently struggling to define this realm. The Institute on Rehabilition Issues, a consortium of Vocational Rehabilitation experts, provides this guidance:

> *Rehabilitation technology includes compensatory strategies and adaptive equipment to increase or improve the functional capabilities of persons with disabilities. It is used to enhance the vocational, educational, and/or independent living opportunities for persons with disabilities. It may be further defined as technological methods of achieving practical purposes in the rehabilitation process. Devices, equipment, and strategies used in this process may be individually created or may be adapted from available equipment or strategies.(Thirteenth Institute on Rehabilitation Issues, 1986).*

Note that the IRI definition of "rehabilitation technology" is slightly broader than the Encyclopedia of Special Education's definition of "assistive devices". This reflects the appropriate life-spectrum concerns of the two areas: learning tools for students and vocational/independent living devices for vocational rehabilitation clients. Included in the IRI definition are biomedical technologies, wheelchairs, adapted vehicles and architechtural modifications, as well as non hardware-intensive strategies, such as job sharing.

Apart from vocational rehabilitation, service delivery in the area of assistive technology has also been provided by speech and language clinics, medical facilities, in research and development settings, by volunteer organizations such as the Telephone Pioneers of America, and by durable medical equipment (DME) dealers. Although this is a new area to special education, these other types of service providers have been involved in the area, albeit without a coordinated or comprehensive approach, and with spotty results, for many years. (Office of Technology Assessment, 1982)

The various components of service delivery include clinical, training and equipment provision aspects. Clinical services are assessment and evaluation (what's there in terms of student needs, capabilities and technology available to meet those needs, and how well is it all working together?) and therapy (formal, goal-oriented practice with the device). The training areas are: training the end-user (student), training caregivers (teachers and therapists), and training parents and significant others (aides, attendants, siblings). The major concerns with regard to equipment are the (1) allocation of resources and, (2) the logistics of distribution.

BACKGROUND

With regard to providing communication aids, environmental controls and computer access systems to end consumers there have been two seemingly insurmountable problems confounding the effort: funding of high cost device systems and provision of ongoing student evaluation, training and follow-up therapies. In the past, locating a device which could provide the needed functions was also somewhat challenging; that at least has changed considerably with the current flock of multi-functional devices which can be accessed using a number of input techniques, and which in turn provide a wide number of output options.

The reasons given for the funding problem range from the relatively high cost of systems ($2000 - $12,000) to the unproven, or at least inadequately documented, efficacy of these tools as vocationally or educationally sound and necessary expenditures. Lack of professional expertise and available services for describing, then locating or designing the devices, training their use and providing the therapies (occupational, physical and speech/language) needed to use them is well known. The widespread availability of this technology is so recent that colleges are only beginning to offer comprehensive professional or pre-professional training programs for these disciplines using state-of-the-art technologies. As is traditional with human service professions, insufficient resources have been applied to achieve results in keeping with current knowledge. Unlike engineering or medicine, speech therapy and special education classes at the graduate and undergraduate levels have not kept pace with current technology practice. At present, only a handful of college programs training speech therapists offer even one course inaugmentative communication. Instead, such efforts have evolved outside the tradional training grounds, through in-services, manfacturers' workshops, conferences and continuing education offerings. Consequently, expertise is still diffuse, and it's development is not yet well-supported.

The approach taken by the Pennsylvania Special Education Assistive Device Center addresses these problems in a new way by achieving a critical mass of technology availability and awareness in a segment of the target consumer population. With adequate equipment, technical support and opportunities to participate in training activities, a strong local network of expertise naturally forms. Using this approach, economies of scale and a cost-effective, ongoing service delivery system are being built for the school-aged and preschool aged subset of the total client population which could benefit from the judicious application of these technologies. The program is in its third year of operation. Feedback from the intended service consumers (teachers, therapists, students) and from professional colleagues has been strongly supportive of the approach. Results are being continuously monitored through daily contact with local specialists and administrators, as well as more formal advisory processes and user surveys.

METHODS

The Pennsylvania Special Education Assistive Device Center (ADC) was conceived to provide appropriate and necessary technology to preschool and school-aged handicapped children in the state of Pennsylvania. In fact, the project has focussed more heavily on communication, writing and computer access aids than on sensory, environmental control, mobility or independent living aids. This decision was made because the population in need of communication, writing and computer access devices was seen to be the most underserved in past programs in the state at the time of this program's inception. In other words, we targeted the multiply physically handicapped students for whom little programmatic or technology expertise had existed to enhance educational opportunities in the past. Mobility needs were not addressed, per se, because of the cost involved and vast population needing such services; the responsibility of the LEAs and their existing relationships with private and public medical service providers was felt to take precedence with regard to wheelchairs, walkers, standing devices and transportation issues. Communication, computer access and writing aids can be appropriately addressed through astate-wide education agency program. It is true that a child who is inadequately positioned cannot hope to operate an assistive device effectively; for this reason the PA-ADC has employed a Seating and Positioning Specialist, and does address the area of device positioning, designing custom trays and switch mountings, and drawing attention to certain occupational therapy principles. Fortunately, commercially available aids have improved steadily over the past several years and now offer more reliable service and a variety of applications. Commercially-available seating systems which are modular and appropriate for our students are now much more widely in use.

The program is administered by the Central Pennsylvania Special Education Regional Resource Center (SERRC). SERRC has an ongoing educational service delivery network of some twenty years duration. It manages a large lending library of professional materials (including software), conducts workshops and inservice training on-site throughout the state, and most recently has been providing specific technical expertise and centralized laboratory style training in educational computer applications. There are 16 professional positions associated with operation of the Central SERRC. Two other Regional Resource Centers in the eastern and western parts of the state operate similar programs. All Resource Centers are funded by the Pennsylvania Department of Education, Bureau of Special Education. The Pennsylvania ADC program under discussion here is a statewide program; however, it was initiated and is administered by the Central SERRC.

The Central SERRC is located in Harrisburg, the State Capital. The ADC is headquartered in the Elizabethtown Rehabilitation Hospital, a historically pediatric rehabilitation center 15 miles away. Staff at the ADC consists of the following five professional roles and backgrounds, with two support (clerical, secretarial) postitions: coordinator (M.S. - Educational Technology), augmentative communication specialist (CCC-speech), positioning and seating specialist (OTR/L), assistive device specialist (M.S. - Instructional Technology) and rehabilitation engineer (M.A. - Rehabilitation Engineering).

For the past five years, the Bureau of Special Education has operated a "Minigrant" program through the SERRCs. The Minigrant program is designed to distribute technology to special education classrooms using PL 94-142 funding. That is to say, such federal funding as is allocated and distributed based on the numbers of handicapped children served in a given geographical/locally-administered area. In Pennsylvania the Minigrant and ADC programs are bothfunded through 94-142. Teachers and therapists compete by writing small grant proposals delineating their need and plans for specific equipment. The grants are then processed through the appropriate SERRC for funding. During each of the past five years, $800,000.00 worth of high technology hardware and software, including classroom computers and sensory aids, were distributed by this program. Out of this successfully-operating program in the state was created the cornerstone of the Assistive Device

Center's Program Plan - its Long-Term Equipment Loan Program.

The Assistive Device Center was originally structured (in 1984) to support three full-time staff people serving as inservice trainers and technical advisors for therapists and teachers needing access to such expertise statewide. In fact, the actual organizational plan which led to the development of the Pennsylvania Assistive Device Center follows the blueprint provided by the National Association of Directors of Special Education (NADSE) in 1980. The general plan of services seems entirely appropriate, even seven years later. As educators were surveyed over time, their interest in and need for expanded services in this area became apparent. A statewide "Awareness" conference in the fall of 1985 attracted the attendance of over 300 administrators and classroom personnel. The equipment requirements and the necessity of ongoing training in student needs identification, equipment function and application was readily apparent. Consequently, the Department of Education, Bureau of Special Education responded positively to the program plan presented in 85-86, allocating $500,000 to fund an assistive device loan program and also providing sufficient resources to add 2 professional staff to implement such a program.

RESULTS

The most frequently asked questions about this program include insurance concerns, equipment transition (from school to work or independent living settings), and concerns about adequate student assessment and follow-up services. One unifying philosophical strand dictates the way that these concerns are addressed in the program. Cooperative relationships among agencies and students are both required and supported by the ADC program. Ultimate responsibility for the success/usefulness of any technological aid system must rest with the end consumer. Along the way to achieving that goal of ultimate control over individual independence, local agents come heavily into play. Over the course of the students' school career, those individual professionals involved with the student change, and even the students' educational or home setting inevitably undergoes change. Thus, no one professional or one agency or one program can assume continuous responsibility for services, cooperation or coordination of efforts. Consequently, the ADC loan program focuses on the individual student as the consistent, unifying agent for his/her own services. Devices are loaned, not to classrooms or to therapists, but to individual students for the duration of their need for that system, or until severance from special education services. Currently, options for funding the transition of functional equipment from school to work or independent living settings are being explored with other state and private agencies. In the wake of the Rehabilitation Reauthorization Act this year, the Pennsylvania Assistive Device Center is actively seeking to provide input to state-wide planning efforts with the Office of Vocational Rehabilitation and other agencies such as United Cerebral Palsy. Minnesota provides an excellent model for such statewide consortia. (Minnesota Governor's Issue Team, 1986, and Minnesota Governor's Planning Council, 1984). Some creative and uniquely cost-effective strategies have been suggested.

Local Educational Authorities (LEAs) are required by the ADC loan program to insure equipment, and to guarantee its availability to the student at all times, including at-home use and use during vacation periods. LEAs are also encouraged to make personnel available for training offered by the ADC. These local efforts are supported by a network of Local Augmentative Specialists (approximately 90 throughout the state) appointed locally by the Directors of Special Education. In an effort to de-centralize equipment knowledge, assessment techniques and therapy ideas, the ADC provides tools and ongoing training regionally for these specialists. Since turnover is relatively high among school personnel, such ongoing training is required and will continue to be a major need even as expertise is developed by individuals. It is a tenet of this program that effective follow-through services, although instigated and supported by the state agency (acting through the ADC program) must be maintained by the local personnel directly involved with the student on a daily basis. This approach reduces the previous emphasis on the prescriptive phase of device application, placing such emphasis instead on the follow-through phase.

DISCUSSION

Methods of gauging the effectiveness of this program are being devised. A recent ADC-sponsored symposium (3/87) brought together academically-affiliated professionals from Pennsylvania and nearby states to examine research issues which could be addressed, given access to the client population of the project. Among the wide-ranging issues identified were concerns with device usage, communicative competency training of users and the appropriateness of cognitive demands placed on system users. While an important part of the overall effort is to examine and improve the service offered, we practitioners must seek to involve the research community in taking an unbiased measure of the actual effectiveness of these systems and strategies, once applied. Anecdotal reports and case studies need to be joined by longitudinal research with larger subject pools. Through this program, we can offer researchers access to such a group of potential subjects.

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ARGUMENTS FOR REHABILITATION ENGINEERING SERVICES

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ABSTRACT

Economic and DRG-related pressures jeopardize delivery of rehabilitation engineering services. Hospital and rehabilitation center administrators must be convinced that these services can impact positively on the ratio of revenue-to-expense. This paper presents such arguments.

THE PROBLEM

Rehabilitation engineering services are available to a very small segment of the disabled community. Furthermore, improvements in this situation are coming at a very slow pace. Technological advancements and availability of new and improved equipment far exceed the opportunity of the rehabilitation engineering community to deliver them.

Clearly, this is true because many hospital and rehabilitation center administrators are very reluctant to employ rehabilitation engineers and to establish rehabilitation engineering departments. They do not understand or appreciate the value of this service, in fact, some of them regard technical services as "frills". These highly business-oriented administrators know very well the revenue-producing services in rehabilitation are physical, occupational and speech therapies. They are convinced that provision of rehabilitation engineering services will only add to operating expense while generating, at best, uncollectible revenue. Somehow they understand that the acute hospital absolutely must invest in the latest and costly equipment and technical personnel, but they cannot transfer this knowledge to the rehabilitation sector.

Rehabilitation engineers are naive enough to believe that performance of good and effective work will establish and assure them of a firm and ongoing position in the rehabilitation services arena. Unfortunately, they are wrong. Engineers, as well as administrators, are part of the problem.

PROPOSED SOLUTION

Presentation of Arguments

The rehabilitation engineering community must present positive arguments to hospital and rehabilitation center administrators based upon one central them - economic impact. It must be remembered that the primary mission of such administrators is to achieve and maintain "fiscal viability". Quality of service and humane considerations are of little importance, unless they bear directly upon cost containment or attraction of paying customers. Even arguments citing indirect advantages must emphasize positive effects upon present and future revenue-to-expense ratios.

Generation of Revenue

It must be remembered that financial performance of the rehabilitation engineering department will be compared to that of the physical therapy department where fees are equal or slightly higher than those of rehabilitation engineering and where utilization rate is ordinarily about seventy percent. The relatively large size of the physical therapy department comprises a great advantage since overhead, such as administration and clinical assistance, can be distributed over a broader base.

The primary counter to this situation is to recognize it and to project improvement in financial performance in the future as the rehabilitation engineering department grows. It should also be emphasized that a major part of revenue accrued by the rehabilitation engineering department will be collectible. This is true because a greater portion of these services are provided to spinal cord injured patients who are covered by private insurance. This group of patients also requires more equipment and services than head injured or stroke patients.

Growth in revenue and in size, which in turn will produce more revenue, is clearly predictable because successful rehabilitation outcomes are increasingly dependent upon technological means in all of the therapies. Speech therapy is becoming "communication therapy" which inherently demands the use of sophisticated communication devices and systems based upon computer technology. Physical and occupational therapies are utilizing functional electrical stimulation, special muscle function and evaluation systems and mechanical exercisers to augment and increase the number and effectiveness of the therapies that they deliver. Physicians and psychologists are increasingly relying upon computer-based diagnostic and therapeutic systems including new and exciting biofeedback systems. Patients, third party payers and accreditation organizations are increasingly recognizing and demanding such technological-assisted services. Clearly, the demand for rehabilitation services is accelerating with time. This fact must be impressed upon hospital and rehabilitation center administrators because it means that direct revenue for rehabilitation services will inevitably increase.

Impact Upon DRG's

Many adminstrators are fearful that presence of rehabilitation engineering services will simply add to expenses and, at best, will result in billing for uncollectible revenue. The primary rebuttal for this contention is that rehabilitation engineering will reduce length of stay - particularly for some of those difficult patients whose hospital stays greatly exceed DRG allowables. This is a most valid argument and many specific cases can be cited.

One example at Kaiser Rehabilitation Center involved a sixty year old man suffering from a stroke and who had very poor seating posture. A large and heavy individual, he slumped forward in his manual wheelchair and stared incessantly at the floor. He was extremely depressed and his posture interfered with his breathing. All this contributed heavily to ineffectual speech and occupational therapy and psychology services. Rehabilitation engineering modified his wheelchair with a firm seat and back and installed strong armtroughs with adjustable tilt. These modifications enabled the patient to sit properly which improved eye-contact, communication and respiratory function. Almost immediate and remarkable improvement in this patient's morale and performance resulted. Therapies became much more effective and the patient was discharged to his home a short time later.

Another case involved a head injured man who was seven years post-injury. This non-verbal patient was a hostile, incoherent individual with severe contractures that forced him to assume a fetal position. His elderly parents wanted treatment for the contractures and to develop a functional communication system. Conventional speech therapy failed to produce a satisfactory communication system and the patient resisted all other therapies and proved to be an extremely difficult patient for the nursing staff. He seemed satisfied only when his radio was playing loudly on the station that he preferred. Discharge planning was difficult because nursing homes did not want him.

Rehabilitation engineering intervened and successfully developed a communication system which not only changed the patient's rehabilitation program but changed his entire life. A large, latching switch for turning the radio off and on was introduced; this was followed by special switches which enabled the patient to operate an Apple computer. The frustration level of the patient decreased and he smiled for the first time in months. He began accepting and participating in his therapies and was discharged with a functional communication system. Intervention by rehabilitation engineering dramatically reduced the hospital stay of this patient and resulted in a most successful outcome! Had this been a DRG-related case, thousands of dollars would have been saved.

Almost all clinical rehabilitation engineers can cite similar cases. Indeed, the role of rehabilitation engineers in reducing length of stay of difficult patients can justify their presence. We must convince hospital administrators of this dramatic fact.

INTRODUCTION OF NEW AND IMPROVED METHODS

Rehabilitation engineering research produces such things as computer-based communication devices, drastically improved seating systems, functional electrical stimulation therapies, biofeedback methods and patient handling and mobility aids. Clinically based rehabilitation engineers introduce these technologically based methods and devices to rehabilitation centers and implements services using them. It is difficult to assess the financial impact of these services but engineers should be encouraged to project and present such estimates to rehabilitation administrators.

Attraction of Patients

Presence of rehabilitation engineering clearly attracts patients, i.e., customers, to the rehabilitation center. This is achieved in a variety of ways including direct inquiries by patients, families of patients and third party payers who learn of new methods and successful outcomes of patients through the media. Other patients are referred by physicians and third party payers who insist upon technological services to assure successful rehab outcomes at reasonable costs. Rehabilitation centers with rehabilitation engineering departments are universally recognized as superior to those which do not. Again, administrators must be reminded of this fact and specific cases where patients came because of need for rehabilitation engineering services should be documented and cited.

Support of Other Departments

Rehabilitation engineering traditionally provides technical support services to speech therapy, nursing, recreational therapy, physical therapy and the administration. Only orthotics returns a like amount of support to rehabilitation engineering. Specific support activities include, (1) provision of technical information, (2) selection of equipment, (3) identification of vendors, (4) maintenance of equipment, (5) design and layout of facilities, and (5) solution of technical problems. Ordinarily, this results in expenditure of 10-20% of uncompensated time which benefits the center but is not recognized by the administrator.

Documentation of the time spent in support activity would result in further loss of time to the rehabilitation engineering department. Possession of this information would, however, serve a useful role in convincing the administrator of the true value of rehab engineering.

Ethics

Unless arguments involving ethics are very closely coupled to loss prevention, they can be ignored.

CONCLUSION

Hospital and rehabilitation center administrators hold the future of clinical rehabilitation engineering in their hands. Many of these people make judgments solely upon revenue-to-expense ratio which invariably indicates that the small rehabilitation engineering department is a "loser". Based upon this criterion and pressures caused by implementation of DRG's and severe competition, administrators are prone to view rehabilitation in a very negative manner. It is not surprising, therefore, that we see rehabilitation centers devoid of rehabilitation engineering services and rehabilitation engineers working without the assistance of a technician. The latter situation imposes a hopeless and extremely frustrating situation which demoralizes and defeats all but the most determined and resourceful engineers. Worst yet, if tends to negate all the efforts of the rehabilitation engineering research community and it deprives disabled individuals of one of their most needed services.

But subjective arguments in favor of rehabilitation engineering services exist. The burden of proof is clearly upon the rehabilitation engineering community which can and must legitimatize, formulate and present them to hospital and rehabilitation center administrators in clear and convincing terms. These arguments must be crystallized by collection, quantification and projection of data - particularly those data that deal with reduction of length of hospital stay and improved outcomes. One powerful approach is to document and cite specific cases.

It is very clear that the future of rehabilitation engineering is in jeopardy. The only way that this situation will improve is through immaginative and vigorous effort by the rehabilitation engineering community.

CALL TO ACTION

RESNA must intensify its effort in promotion of rehabilitation engineering services by continued lobbying, special committee study and action and communication with the hospital and rehabilitation center administrative community. NIHR can provide support by encouraging projects that assess and project economic impact of rehabilitation engineering. The research community which has traditionally ignored service delivery, can be of great help through their ongoing dialogue with administrators. But the primary burden and challenge resides with the clinical, service delivery rehabilitation engineer. We simply must become more business oriented and effectively present our arguments to those who control our destinies - hospital and rehabilitation center administrators.

ACKNOWLEDGEMENTS

The Rehabilitation Engineering Department at Kaiser Rehabilitation Center was established in 1981. Impetus and encouragement for this action was provided by the National Institute of Handicapped Research through the IMPART program. Kaiser Rehabilitation Center also acknowledges the encouragement provided by Southwest Research Institute, Oklahoma Rehabilitative Services and Texas Rehabilitation Commission.

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Special Interest Group 2

Personal Transportation

Chair: L.J. (Lou) Klein, B.S.

Improving Reliability of Personal Transportation Systems

Chairman, S.I.G. 2 - Louis J. Klein

R.E.S.N.A. is concerned with transferring science and technology to resolve the needs of persons with disabilities. The process involves not only needs of the persons with disabilities, but also the evaluation, design, reliability, quality, marketing and use of the end product or new device in the real world.

The Special Interest Group [S.I.G. 2] on personal transportation is dedicated and committed to serving as a catalyst to enhance the process and address those urgent issues which hamper persons with disabilities from participating in the tasks of daily life due to lacks in personal transportation.

In Memphis, Tennessee [1985], the volunteers came forth. In Minneapolis, Minnesota [1986], the builders established the foundation and framework. And now, in 1987, here in San Jose, California, the first S.I.G. 2 Scientific Symposium on personal transportation comes to fruition.

This Symposium is only the beginning of the interchange between the evaluator, designer, manufacturer, provider, standards developers, and consumer.

Personal transportation is a key to attaining "the freedom to travel". "Freedom to travel" has many facets, but a primary one for all travelers, including persons with disabilities, is participation in the necessities of daily living, such as:

- Education
- Employment
- Recreation
- Social
- Shopping for food, clothing, etc.

The 1987 S.I.G. 2 Scientific Symposium shall deal with concepts, designs, products and programs developed to enhance an individual with disability to attain freedom to travel and secure as appropriate the necessities of life. This Symposium shall concentrate on only one facet:

"Improving the Reliability of
Personal Transportation Systems"

The presenters include evaluators, educators, designers, manufacturers, providers, standard developers and consumers.

Another important ingredient is the audience. A give-and-take session has been established so that this Symposium is only the spark that kindles the more comprehensive "in-depth" examination of urgent concerns in the area of personal transportation for persons with disabilities.

The beginning in the search for "freedom to travel for all" is now at hand.

THE CARCHAIR STORY

David J E Constable
Car Chair Ltd

ABSTRACT

Historically, in the UK, if a disabled person wanted vehicular mobility, their choice of transport was limited to entering the rear of a small van, with dramatically restricted vision, or physically transferring from their wheelchair to the front seat of a car. Travelling in the rear of the van the disabled person was isolated from the driver, and the requirement put to me was to design, and ultimately produce, a method for a disabled person to enter the standard car and travel in the front seat position without the physical effort of transferring from their wheelchair. Any system would, of course, have to be safe, beneficial, reliable, durable and easy to use.

BACKGROUND

After completing Engineering College, I had several years experience running my own business in fabrication and creative engineering, working to my own motto "if it is made of metal, I will make it or repair it". A design friend and myself were shown by two disabled people the difficulties they experienced in transferring into the front seat of a car. They did not like the greatly modified mini-vans which gave a very low resale value and at the same time took away the overall strength of the vehicle. We agreed to design a system for entry that would be aimed at making their lives easier and give them greater freedom.

INTRODUCTION

The ultimate aim would be to transfer the wheelchair and occupant safely into the front seat position. Initially, we experimented using the conventional folding wheelchair and a platform entry, but learnt that there was not room for the wheelchair and occupant to enter the door aperture. At the same time, we realised that the wheels would have to be removed, or possibly folded alongside or under the chassis. However, if the wheel tracking were wide enough for safe normal use, it would be too wide to fit into the well of the car, and if folder under the chassis in a motorised chair, the seating would be too high.

METHOD

We realised we would require a lift system inside the car and would have to re-design the wheelchair itself rather than greatly modify the car. There were five main areas of development: the lift; pick-up point; wheelchair chassis; retracting wheels, and wheelchair seating.

The lift

We knew that not only would we have to lift, we had to move the occupant back into the car, which meant we needed a vertical and horizontal lift. We aimed at a single pillar lift for the following main reasons: to incorporate the lift gear within the pillar, to give greater accessibility into the rear of the vehicle, and to ensure there were no cumbersome structures to restrict rear view visability for the driver.

Experiments with hydraulic lifts were carried out but we chose linear actuators which would enable us to have up and down power and independent in and out power.

When installed in a standard two-door vehicle, the lift equipment is attached to the top seatbelt mounting and bolted and plated to the floor, creating a triangulation with the door pillar, thus giving extra strength. The in and out movement is obtained by using a parallelogram frame using a single pick-up point.

Pick-up point

The single pick-up point allowed for the fact that we would be loading and unloading on uneven ground and varying heights, and for allowing the system to be installed for either driver or passenger. It also means there is only one location to make and gives the occupant of the chair greater control when entering the vehicle.

The front of the chassis has two location points which locate securely into the framework bolted to the floor of the vehicle, and the single pick-up point on the rear of the chair features in the lock down system for safety.

Chassis

Since we would be lifting on effectively one corner of the chassis, it had to be tortionally rigid. But, if it was tortionally rigid when being used as a normal outdoor wheelchair, there could be times when one of the drive wheels would be off the ground. This we overcame by incorporating independent suspension on the rear wheels.

We experimented with a tubular space frame chassis but to build into ideal tortional rigidity meant we had tubes in the way of other necessary components. We therefore settled on using a mixture of sheet metal and tube, setting a target safety factor of 280 lbs with a safety factor of 4.

Wheels

The whole success of the project hinged on the ability to somehow get rid of the wheels. If the wheels were left in the conventional position, we could not tie down in the front seat position, which is what we were trying to do. Our ultimate aim was to use the strength of the chassis to secure the chair and occupant safely into the front of the vehicle.

If the wheels folded under the chassis, it would sit too high in the vehicle. If the wheels retracted alongside the chassis, it would be too wide to seat between the door sill and the transmission tunnel of most vehicles. What we actually required was a suitable width track for normal use, but a 19" track when fitted to the front seat position. This restriction on width was also hampered by the need to have batteries, loom, gearboxes and wheels all in a 19" space.

The logical place to have the axles was on the most forward and rearward points of the chassis. Taking into account the wheels would have to be locked in position when being used as a wheelchair, it became evident we had to use some form of hinge configuration. If we did this, the wheels could not be on the rear point of the chassis. We then experimented with a fixed point near the rear and top of the chassis, and a further fixed point towards the bottom centre to create the effect of a trailing suspension swing arm. Naturally when folded the equipment did clear the gearboxes, loom and batteries, but it was still too wide for the vehicle. We could afford, in fact, to have the top of the wheels slightly wider, with the track at the bottom of the wheels narrower, so, in folding the wheels we needed the ability to go through an angular change. But we could not compromise the necessity of the rear wheels to run on the ground in a vertical and horizontal plane. After much searching, we placed the axles in the centre of the chassis at an inclined rearwards angle, and the fulcrum point at the rear of the chassis had to be set at the same corresponding angle. We were therefore able to achieve a safe road going track and the required 19" width for goint into the vehicle.

This created the need to incorporate levers to the rear of the linkage to give the ability to operate the retraction linkage by the user or attendant. This had to be confined in a given space to ensure that they did not get in the way of other parts of the equipment. We also had to modify the original chassis structure because we had to go through the rear of the chassis with the levers, but still retain the overall rigidity.

The wheelchair

Since the wheelchair was not folding in the conventional manner, ie side to side, we had the opportunity to look closely at the wheelchair seating. Rather than make the decision of seating based on simplicity and follow the existing conventional methods, we had discussions with many disabled people with a wide range of personal problems.

Initially, they told us that the seating gave no support; the straight canvass back led to their leaning forward, giving curvature of the spine, and that conventional chairs were inflexible in as much as arms had to be changed when working at a desk.

We therefore had the option of utilizing a moulded seat incorporating lumbar support, which potentially would be much more comfortable. A prototype was therefore made.

The comments from the disabled allowed us to completely rethink the seating and we incorporated adjustable arms, adjustable headrest, adjustable thigh supports (which assist in spreading the weight load and preventing the knees knocking together), and adjustable footrests in both height and angle. Attention was also paid to the Carer, and adjustable height pushing handles were also incorporated. The Carchair cushion, which sits in the well of the fibreglass moulding, can be replaced with the majority of standard medical cushions.

Attention was also paid to home maintenance, such as the use of dry cell batteries, and the convenient overnight battery charging.

We knew that by reclining the back of the seat, comfort and bodily function would be improved, but there were limitations because of the lift system and swinging into the vehicle. We settled on a recline of approximately 4° which is a much more natural seating position, and in fact reduces the direct weight on the ischium by approximately one third, thus reducing the possibility of pressure sores.

CONCLUSION

We have been producing Carchair in the UK commercially for seven years, and keep in close contact with a wide range of our customers. They have told us that since using our Carchair their bladder function has improved and the considerably improved posture has benefited their breathing abilities and they are enjoying a longer and more active daily life due to less fatigue. They have all indicated less visits to their physicians than previously.

We have also learnt that multiple sclerosis patients who have purchased our equipment in the early stages, ie prior to deformation of the spine have benefitted from the lumbar support keeping their spine in it's correct position, thereby helping to slow the progressive deformation and extending their overall wellbeing.

In view of the perceived comfort and benefits of the Carchair, we have been asked to develop an indoor/outdoor motorised wheelchair incorporating the seating and flexibility benefits that in the USA can be used in conjunction with the converted vans.

The Carchair system is compatible with a range of 2-door vehicles, on average the door is some 10" longer than on a 4-door model. The most popular vehicle however, is the 4-door Nissan Stanza Wagon, which is ideal for a wide range of disabilities because of it's unique rear door opening. The suitability of a particular car however, is generally determined by the disability of the prospective user.

In the USA we are linking with experienced van conversion dealers who are fully trained in the installation, maintenance and servicing of the Carchair system, and are able to have a demonstration vehicle on their premises.

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TRANSFER OF CURRENT TECHNOLOGY TO ADAPTIVE DEVICES AND ITS IMPACT ON THE DRIVING PUBLIC BOTH ABLE BODIED AND PHYSICALLY CHALLENGED

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ABSTRACT

This paper outlines the basic criteria that should be applied to the design of adaptive equipment for the physically challenged.

INTRODUCTION

Due to paralysis resulting from a Polio attack as a child, I have always used an adaptive driving aid. I am an engineer by profession and have had a life long interest in the automobile, especially high performance automobiles. I designed and built my first hand control at the age of seventeen. My participation in the design and development of adaptive driving aids, both private and public, along with my participation as a member of the SAE Committee for Adaptive Devices has provided me with an insight into the adaptive devices industry from an engineering perspective. The following engineering criteria should be applied to the design of any adaptive device.

USER INTERFACE

The most important aspect of any adaptive device is that it provide the physically challenged user with the independence of action that most able bodied people take for granted. The user should have convenient access to the vehicle. After entering the vehicle, if adaptive equipment is used it should be placed in such a way that the user has convenient and comfortable access to it. The adaptive device should have minimal intrusion into the space occupied by the user. It has been my experience that most vehicles equipped with adaptive devices are driven by both able bodied and physically challenged drivers, therefore it is most important that the able bodied user of the vehicle have unobstructed access to all the vehicle controls both active and passive.

DRIVER SECURITY

When adaptive equipment is installed in a vehicle it should not interfere or obstruct the intended operation of all vehicle crash systems, i.e. seat belts, collapsible steering columns, soft dash fascia. Something I have found that is often ignored is the relationship between a hand control and the steering column in a crash situation. The steering column collapses, as it is designed to do, but the hand control device may not as it is anchored to the dash steering column support structure. The hand control remains in place putting the driver at risk of physical injury as he impacts the hand control device.

Another item that is often not addressed when designing adaptive equipment is the "G" forces encountered in a vehicle crash situation. I have often seen adaptive devices attached to the vehicle with sheet metal screws rather than nuts and bolts in conjunction with the proper back up plates. The designer of adaptive equipment should understand the dynamics encountered in a vehicle crash. The average "G" forces encountered in the 30 mph barrier crash for a van is 28-35 G's and 22-30 G's for a passenger car.

DURABILITY

It is essential that any adaptive device designed for use in motor vehicles have a minimum design life equal to that of the vehicle, 10 years or 100,000 miles should be an absolute minimum. The purchaser of adaptive equipment used in motor vehicles, because of his or her physical impairment, is counting on these devices to operate properly every time they are used. Therefore it is essential that adaptive equipment be of the highest quality to minimize the possibility of a mechanical failure.

SERVICEABILITY

Adaptive equipment should be designed with zero maintenance as a design goal. In those situations where regular scheduled maintenance is unavoidable, the procedure should be made as convenient and as easy to accomplish as possible. The service procedure should not lose sight of the fact that a physically challenged person may well be the person performing the service.

VEHICLE INTERFACE

Adaptive devices should be designed to have a minimum impact on the resale value of the vehicle when the adaptive device is removed and the vehicle is sold. The physically challenged consumer should not have to absorb depreciation in resale value of a vehicle because of irreversible interior alterations that a second able bodied purchaser would find unacceptable.

ACCEPTANCE

Several years ago the Veteran's Administration developed test standards for hand controls and wheelchair lifts. This was certainly a most important first step toward realistic performance criteria for these devices. These performance standards assured the physically challenged consumer that the products bearing the V.A. seal of acceptance were properly engineered and of high quality. At the present time, work is in process to develop standards for adaptive equipment, both here in the United States and internationally. As this work is completed and implemented the physically challenged consumer will be the primary beneficiary. The adaptive products being purchased will meet these basic design and performance standards.

COST

Adaptive equipment should always be designed for lowest cost to the consumer without compromising quality. With the emergence of third party funding, adaptive equipment costs tend to rise. The adaptive equipment manufacturers should be ever striving to keep his product cost within the financial capability of the unassisted consumer.

SUMMARY

In recent years, the physically challenged have become much more vocal and demanding in regard to physical access and mobility. These people are no longer satisfied in not being a part of the mainstream of society. They want to participate and live their lives to the fullest. Properly designed adaptive equipment will have a major impact in helping these people meet their goals.

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PERFORMANCE STANDARDS FOR ADAPTIVE EQUIPMENT IN PERSONALLY LICENSED VEHICLES USED BY PERSONS WITH DISABILITIES

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&
E. P. Doolittle, Chairman, SAE Adaptive Devices Subcommittee

ABSTRACT

A Society of Automotive Engineers (SAE) Subcommittee has been established to develop SAE voluntary performance standards, recommended practices, and information reports relating to adaptive equipment in personally licensed passenger vehicles used by persons having a disability. The Subcommittee, composed of manufacturers and other experts from the rehabilitation community, is working on SAE documents for (a) adaptive driver controls, (b) wheelchair lifts, (c) wheelchair occupant protection systems, and (d) related terminology. Additionally, test templates and a computer program (with user's guide) have been developed for predicting wheelchair storage capability in the trunk or behind the seat of passenger vehicles.

INTRODUCTION

In 1976, the first Personal Licensed Vehicle National Workshop was held at the request of the President of the United States. A Second workshop was held in 1983, at which it was reaffirmed that product performance standards for mobility hardware used in personally licensed vehicles should be a high priority issue. From that workshop came a call to the Society of Automotive Engineers (SAE) to spearhead an effort to fill the need for such standards, a need that has been reiterated time and again by state agencies, driver educators, and third party providers.

The Adaptive Devices Subcommittee of the SAE Human Factors Committee was established to meet this need, and has been actively researching and developing standards. This paper presents a summary of the progress made to date.

Adaptive devices for personally licensed vehicles includes equipment that alters or substitutes for an original equipment manufacturered (OEM) component to accommodate the capabilities of a person with a disability. As its initial charge was generated in the field of personally licensed vehicles, that is where the SAE Subcommittee is focusing its attention, at least for now. Wheelchair tie-down equipment for buses and other forms of public transportation, for example, is not being addressed at this time.

WHAT IS SAE?

The Society of Automotive Engineers is a widely recognized professional society which has been developing voluntary standards for mobility industries since 1902. In that time, SAE procedures have been established for careful review and balloting of official documents drafted by its committees and subcommittees to ensure that SAE Standards, Recommended Practices, and Information Reports are reasonable, appropriate to the need, and represent a consensus of the experts who have prepared them.

SAE policy also requires broad representation in the groups which develop these documents to ensure consideration of all points of view. The Adaptive Devices Subcommittee is composed of individuals from advocacy organizations for disabled persons, vehicle and adaptive equipment manufacturers, state regulatory agencies, occupational therapists, driver trainers, the Veterans Administration, and other experts from the rehabilitation community. Although individuals who participate in SAE committees bring with them the expertise they have gained through their work, they serve the SAE as independent experts. There are no corporate or organizational members, nor does any member "represent" his or her employer. Individuals involved in developing SAE standard documents work as volunteers. SAE does not pay for their time or travel expenses, although many employers recognize the need for the work of the SAE and underwrite travel expenses.

Most of the documents developed by the Adaptive Devices Subcommittee will be published in the SAE Handbook, or perhaps in a separate bound volume. The use of SAE standards and recommended practices is purely voluntary. Manufacturers of devices covered by SAE specifications can certify to customers, often through package labeling and/or advertising claims, that the products meet the applicable SAE requirements. However, purchasing agents often specify that a product meet applicable SAE standards as a condition of purchase, and regulatory agencies have adopted SAE documents as a basis for rules and regulations.

THE SUBCOMMITTEE'S ACTIVITIES

Shortly after its formation, the Adaptive Devices Subcommittee had to select a focus for its initial activities. The subcommittee generated a list of 27 possible issues as candidates for standards action, and then ranked them by ballot. This resulted in a decision to begin the tasks discussed below.

Adaptive Driver Controls

Of the three recommended procedures under development, the most progress has been made on a draft document entitled "Recommended Practices for Automotive Adaptive Driver Controls, Manual." This document (quoting directly from its Scope statement) "establishes a uniform procedure for assuring the manufactured quality, installed utility, and service performance of certain automotive adaptive products, other than those provided by the vehicle manufacturer, intended to provide driving capability to persons with physical disabilities. These devices function as orthotic appliances to compensate for lost or reduced performance in the arms and/or legs of the driver. Some of the devices are designed to transfer foot functions to the hands, hand functions to the feet, or functions from one side of the body to the other." The recommended practice primarily applies to "those controls, operated by the driver, which directly affect the direction and rate of the moving vehicle, including the steering, brake, and throttle controls." Other controls are covered as well.

The first draft of this recommended practice was written under contract to SAE by an outside research organization which had expertise in adaptive driver controls. The existing Veterans Administration standard provided a starting place for this work, and the experience of a major automobile manufacturer in testing a hand control design contributed to the refinement of the test procedure. A Task Group of the Adaptive Devices Subcommittee has completed its revision and editing of the document.

The recommended practice, as currently drafted, included recommendations for design and manufacturing quality, documentation such as installation, operating and maintenance instructions, and a series of performance tests and requirements. In the tests themselves, the hand control samples are subjected to 4 hours of vibration, fifty hours of exposure to a salt water fog environment, 250,000 operating cycles with significant control force application (for instance, 50 pounds on the brake control), and a static overload test. Upon completion, the unit must still function properly and not show signs of visible deformation or other problems.

This past winter, a contract was awarded by SAE to validate the test procedures in the draft document by trying the test procedures, using a representative number of commercially available adaptive driver controls. In addition to actually conducting the tests, the contractor will carefully analyze the procedure itself for possible improvement. If all goes well, the recommended practice may receive final approval before the end of the year.

Wheelchair Lifts

Some progress has occurred in the development of a recommended practice for wheelchair lifts, those battery powered hydraulic or mechanical systems designed to raise and lower an occupant in his/her wheelchair between the ground and the van floor in order to enter or exit a van. An outside research organization, working under contract to SAE, prepared a first draft of a recommended practice for wheelchair lifts. Once again, the VA standard and the experience of manufacturers, installers and providers have been blended with the contractor's work by a task group to create a more comprehensive and otherwise improved document. The task group is now editing that document.

Wheelchair Occupant Protection Systems

Wheelchair occupant protection systems (WOPS) are defined as total restraint systems intended to provide crash protection for drivers and/or passengers seated in wheelchairs. These systems usually are installed in vans. Included is a system for wheelchair tie-down as well as a separate but complimentary system for occupant restraint. A vehicle may also contain a wheelchair tie-down mechanism for securing an unoccupied wheelchair inside the passenger space against passive movement during vehicle operation.

It is not surprising that a wheelchair-seated occupant in a motor vehicle wants the same protection as is given to his/her counterpart seated in a factory furnished seat, making use of a factory furnished seat-belt or other available restraint system. However, this is without doubt the greatest challenge the Adaptive Devices Subcommittee faces, because wheelchair occupant protection is a complicated task. Wheelchairs are not designed to be seats in moving vehicles. To design them to provide the strength of an OEM seat would make them far less useful for their primary purpose because their weight probably would be increased significantly. Seat belt routing is difficult with the structure of a wheelchair. Many of the occupants have restricted arm use and strength, making manual donning and adjustment of a seat belt difficult if not impossible unassisted.

Add to these facts the economic difficulties of conducting crash tests, relating to the small size of the WOPS market and the companies that serve it. The WOPS manufacturer will be lucky to be able to conduct a few sled tests which replicate the dynamics of more expensive vehicle crash tests. The Adaptive Devices Subcommittee hopes to provide sufficient guidance through the yet to be written recommended practice that reasonable protection will be provided without prohibitive test and development cost.

A task group from the Subcommittee is considering the issues that must be addressed in formulating any recommended practice. To assist in this process, a report has been prepared under contract to SAE by a consultant which identified the state-of-the-art and the current practices relating to wheelchair occupant protection systems, and to crash test methodologies. Although much has been done already, this important task had no existing standard to use as a starting point, and is by far the most complex.

Wheelchair Accommodation in Passenger Vehicles

Some wheelchair users are able to drive or ride in a sedan, provided their wheelchair can be stored during the trip behind the front seat or in the trunk. Wheelchair storage capability in passenger vehicles depends, of course, on the dimensions of both the sedan and the wheelchair.

The Adaptive Devices Subcommittee has under development a service that should allow a wheelchair user to determine whether a car will accommodate his/her wheelchair. Two approaches for predicting this type of wheelchair accommodation have been developed under contract with SAE. One approach involves an IBM compatible computer program for predicting wheelchair storage capability for given sedans and wheelchairs. The other involves a plastic template to physically test automobiles for wheelchair fit.

In field trials, it was determined that the templates have only limited practical utility, so further work on them has been terminated. However, the computer program works well and looks like it will be practical. A Working Group of the Subcommittee now is planning further field tests to check the accuracy of the computer program's predictions and its usefulness in actual field use.

The idea is to have the program available at rehabilitation facilities, car and wheelchair dealers, or even automobile company customer service offices. The wheelchair user can contact one of these facilities, give the dimensions of his or her folded wheelchair, and find out whether a specific car being considered will accommodate the chair. A list of cars that accommodate the dimensions of a specific wheelchair can be printed. The program will also allow someone who already has the car and is about to acquire a wheelchair determine the maximum dimensions of a wheelchair that can be accommodated.

Negotiations have begun with a well known company that provides vehicle dimensions to the collision repair industry to provide the specific dimensions needed each year to make the program work for all the new models. Hopefully, this program and data updates will be available from SAE within a year, or a year and a half.

Terminology

A list of definitions for key terms related to the work described above is being tabulated by a fifth Working Group from the Subcommittee. The first draft of this list was compiled through an SAE contract. Additions and modifications are being made as suggestions are received from the other four Working Groups. This working group keeps everyone talking the same language. When the work reaches publication, it is the hope of the Adaptive Devices Subcommittee that the rest of the rehabilitation community that deals with these devices can accept the common terms established in this effort.

ACKNOWLEDGEMENT

Financial support from the National Institute on Disability and Rehabilitation Research (NIDRR), formerly the National Institute of Handicapped Research (NIHR), has enabled the Subcommittee to expedite contract work for surveying existing equipment and standards, and for developing and testing proposed standards. With this much appreciated support, the task groups have made significant progress.

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DRIVER ASSESSMENT, EDUCATION AND TRAINING FOR THE DISABLED

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ABSTRACT

The Louisiana Tech University Center for Rehabilitation Science and Biomedical Engineering sponsors a comprehensive driver assessment, education and training program for persons with disabilities. The program uses a multidisciplinary team approach, with the team members being determined by the individual needs of each client. The program is organized into three major components, Driver Assessment, Adaptive Device Prescription, and Driver Education and Training. In addition, a Mobile Assessment Laboratory has been developed in an effort to solve the problem of providing assessment services to individuals who find it difficult to travel long distances to rehabilitation facilities.

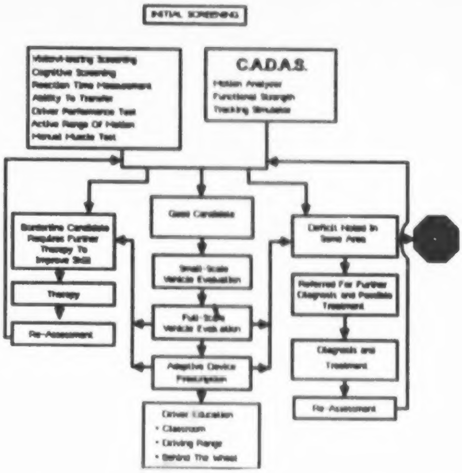
BACKGROUND

In 1978, through a cooperative agreement with the Louisiana Division of Vocational Rehabilitation, a driver assessment, education and training program was established at Louisiana Tech University. In 1983, as a result of the success of the program, the National Institute of Handicapped Research designated Louisiana Tech University as the National Rehabilitation Engineering Center for Personal Licensed Vehicles for the Disabled. Objectives of the program are related to the development and appropriate use of technology in meeting the personal transportation needs of persons with disabilities.

SCREENING AND ASSESSMENT

The driver assessment, education and training program at the Center uses a multidisciplinary team approach, with the team members being determined by the individual needs of the client. Those involved in the program include: clients and their families, physicians, referral sources, funding sources, occupational therapists, rehabilitation engineers, driver education instructors, vehicle modifiers, department of motor vehicle personnel and various consultants.

The program is organized into three major components, Driver Assessment, Adaptive Device Prescription, and Driver Education and Training. The following flow chart illustrates the sequence of activities from the initial screening process to the conclusion of the driver education course.


INITIAL SCREENING
Vision/Hearing Screening
Cognitive Screening
Reaction Time Measurement
Ability To Transfer
Driver Performance Test
Active Range Of Motion
Manual Muscle Test
C.A.D.A.S.
Motion Analyzer
Functional Strength
Tracking Simulator
Borderline Candidate Requires Further Therapy To Improve Skill
Good Candidate
Deficit Noted In Some Area
Therapy
Re-Assessment
Small-Scale Vehicle Evaluation
Full-Scale Vehicle Evaluation
Referred For Further Diagnosis and Possible Treatment
Adaptive Device Prescription
Diagnosis and Treatment
Re-Assessment
Driver Education
• Classroom
• Driving Range
• Behind The Wheel

Following are descriptions of the various program components.

Initial screening

Medical information and driver pre-assessment forms are received at the Center for review by the assessment team. The client must be able to meet state licensing requirements to be considered for services.

Driver Assessment

Vision screening. Vision testing equipment is used to screen the person's: visual acuity, field of vision, depth perception, phoria, color vision, night vision, glare vision, and glare recovery. If any deficits are noted, the client may be referred to a vision specialist for further evaluation and/or possible driving restrictions.

Hearing screening. An audiometer is used to provide a gross measurement of the client's effective range of hearing. The deficits are noted. If any deficits are noted, the client may be referred for a further evaluation.

Reaction time measurement. A computerized search and reaction test measures simple and complex reaction time.

Cognitive testing. The Motor Free Visual Perception Test and the Baylor Adult Visual Perception Test are used as a screening for visual-perceptual ability. Other psychological tests may be administered to screen for specific deficits if deemed necessary by members of the assessment team.

Driver performance test. This is a videotape presentation of driving situation selected to determine a driver's ability to perform the visual-perceptual and decision-making tasks required for operation of a motor vehicle in the highway transportation system. The client is asked to choose from multiple choice responses after viewing traffic scenes. Test results give the evaluator information regarding the client's ability to Search, Identify, Predict, Decide and Execute in the highway transportation system. Test scores have a high correlation to the potential traffic accident involvement of the driver.

Ability to transfer. This is an evaluation of the client's ability to: 1) lock/unlock and open/close the door, 2) transfer from their wheelchair to the driver's seat, 3) secure the wheelchair for driving, 4) remove the wheelchair from the secured position, and 5) transfer from the driver's seat into the wheelchair.

Active range of motion. The client's active range of motion, which can be described as the movements a client can make without assistance, is measured by an occupational therapist.

Manual muscle test. A standard manual muscle test is administered by an occupational therapist to those clients presenting with muscular weakness associated with their disability.

Computer-assisted driver assessment system (CADAS)

The Computer-Assisted Driver Assessment System is an important part of the program. As a component of the driver assessment system, CADAS provides the evaluator with objective data relating to the ability of the client to operate adaptive driving controls and devices. The CADAS consists of three devices, operated by a menu driven system with an IBM-XT microcomputer.

Motion analyzer. The motion analyzer is used to measure the movements the client is able to make without assistance. As the client performs the motions necessary for operating adaptive driving controls, the device measures a set of pre-selected points. The evaluator also uses the device to measure points (height, eye level, wheelchair dimensions, etc.) important in determining vehicle modifications and driver position recommendations. The system produces a graphic representation of these points to accompany a list of points and their three-dimensional measurements.

Functional strength analyzer. The functional strength analyzer is used to gather data regarding the client's ability to apply force for steering and brake/accelerator control functions. This device measures the amount of force applied at various steering wheel positions, steering device positions and brake/accelerator control angles. The force measurements are printed in table form to allow the evaluator to easily compare test results. These data aid in determining: 1) the most effective steering wheel angle, steering system effort and steering device for the client; and 2) the most appropriate position and type of brake/accelerator control device for the client.

Tracking simulator. This is a computer controlled device that measures the ability of a person to perform the basic control motions necessary to operate a motor vehicle. The potential driver uses adaptive driving controls to perform a tracking task generated by the computer program. The system produces a printout of the results that allows the evaluator to compare the client's ability to operate a variety of adaptive controls.

Small-scale vehicle evaluation

This evaluation is a measure of the client's ability to control a vehicle in a dynamic situation. The Small-Scale Vehicle (SSV) is an electric golf car that has been modified to accept variety of adaptive driving controls. A driving range with dimensions suitable for the SSV has been designed and built. This facility allows the driving evaluator the opportunity to assess the client's performance, while allowing the potential driver to practice basic vehicle maneuvers with appropriate adaptive controls. Features of the SSV include; a variety of control options, a high degree of safety, low cost and its use as both an assessment and a training tool.

Full-scale vehicle evaluation

The driving candidate operates a full-size assessment/training vehicle in order to determine: 1) the appropriateness of the controls used on the Small-Scale Vehicle, 2) the client's need for the placement of secondary control adaptations, 3) the client's need for power steering and brake backup systems, and 4) final recommendation of adaptive device needs.

After the assessment is completed, the evaluation team confers and makes recommendations in regard to the client's potential for driving. One of four conclusions are made by the team. These are 1) the client exhibits good potential for driving and should continue on with the program, 2) the client is not a good candidate for driving and the appropriate agencies are notified, 3) the candidate shows a potential for driving, but will require further therapy to improve functional skills, and 4) a deficit in some area is noted and further diagnosis is recommended. After therapy, diagnosis and/or treatment, a re-evaluation is provided.

ADAPTIVE DEVICE PRESCRIPTION

Based on the results of the assessment, an individualized prescription is written for the client. This includes a detailed list of vehicle modifications and adaptive equipment needs. The prescription is written to be as cost-effective as possible without compromising the safety of the client or other highway users.

The client also receives information relating to appropriate vehicle selection, funding sources, vehicle and adaptive equipment installation and maintenance, insurance and driver licensing requirements and procedures.

DRIVER EDUCATION AND TRAINING

The Center's Driver Education and Training program includes three phases of instruction. Classroom, driving range, and behind-the-wheel activities are integrated to provide clients with the learning experiences that will help them become appropriate users of the highway transportation system.

Classroom

This phase of the program is performance-based to allow for the individual learning styles and instructional needs of the clients.

Driving range

These activities are designed to give the client the opportunity to practice and routinize basic vehicle maneuvers while using the best-suited adaptive driving controls.

Behind-the-wheel

Behind-the-wheel instruction will vary for each client, depending on his or her ability to acquire the basic skills necessary for operating appropriately in the highway transportation system. An On Road Performance Test is administered to evaluate a driver's responses to representative driving situations. It is a comprehensive test for assessing the driver's ability to make and properly execute good and timely decisions in traffic situations.

MOBILE ASSESSMENT LABORATORY

One of the components of the program developed through the National Institute of Handicapped Research project is the Mobile Assessment Laboratory. This is a specially equipped vehicle designed to be a self-contained assessment facility. The Mobile Laboratory can be driven to a rehabilitation center, where the driving capabilities of several clients can be evaluated over a short period of time. The assessment team includes an occupational therapist and a driving instructor. Assessments conducted in the Mobile Laboratory include all of the tests used in driving assessments at the Center, with the exception of the Small-Scale Vehicle and Full-Scale Vehicle evaluations. Clients may then be referred for further evaluation, driver education and training or appropriate therapy. The Mobile Assessment Laboratory may offer a solution to the problem of providing assessment services to those individuals who find it difficult to travel long distances to rehabilitation facilities.

ACKNOWLEDGEMENTS

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AN ASSISTIVE MOBILITY DEVICE FOR INDEPENDENT LIVING

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ABSTRACT

Traditional shopping devices do nothing to remove the loads and stresses from the shopper's joints. In addition, the loading and unloading of goods and parcels to and from an automobile trunk is a difficult task in itself. However, for the elderly and arthritic, the removal of loads and stresses is a requirement for their health, safety and comfort. It is proposed that the use of a cart and lift mechanism could virtually eliminate the load from the user.

INTRODUCTION

The needs of the elderly and arthritic have, for the large part, been ignored. There is a great necessity for useful and desirable products for this population. One obvious area that needs to be addressed is the problems which this user population confronts in the seemingly simple task of shopping. An assistive device that easily transports goods and offers greater independence to the user is needed.

BACKGROUND

The elderly and arthritic population requires special assistance and to accommodate their needs. Some assistive devices are available to these users but are often unappealing and lacking the proper functions. The simple task of shopping becomes a difficult process for the physically disabled. The use of common shopping carts and/or paper bags creates a potentially hazardous situation or at a minimum, causes the users discomfort. The fact that shopping carts are suppose to remain on the store's property along with the poor maintenance of many shopping carts make their use inconvenient if not impossible. The physically disabled person is forced to forfeit some of their independence and rely on outside assistance. There is clearly a need for an assistive device that easily transports goods and that offers greater independence to the user population.

CONCEPT

A combination of two products into one system; a cart and a lifting mechanism was the chosen method of solving the stated problem. The cart, in conjunction with the lifting mechanism, supports the weight of parcels or goods to be transported, thereby taking any load off the user.

The cart itself is collapsible. This provides a compact easily transported form that has minimal storage requirements. When extended to operative position, the cart provides an easily maneuverable device for transporting goods. The cart's aesthetic qualities are designed to not have the appearance of a medical or assistive device.

The lifting mechanism which is housed in an automobile trunk and designed to fit the minimum trunk space, raises to load goods directly to and from the cart. The mechanism lowers any items to be stored in the trunk's floor thus maximizing the trunk's storage space.

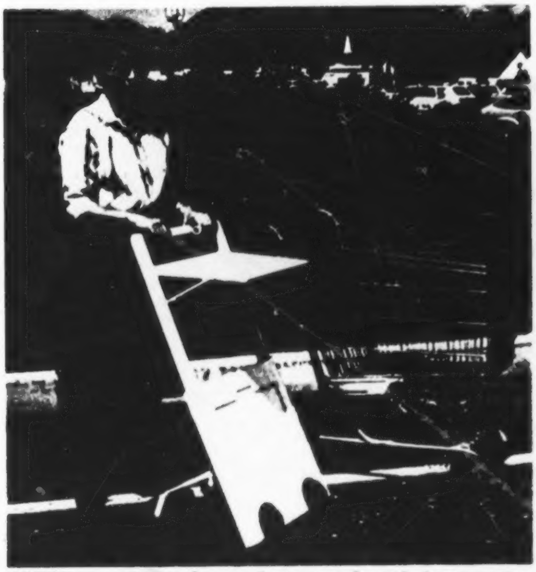


FIGURE 1: Comparison of proposed cart to common shopping cart.

PRODUCT DESCRIPTION

A step by step description of the cart and lift mechanism focuses on the details of the system. The cart, when folded up, offers an ergononically shaped handle in its center so carrying the unit is comfortable with only one hand. Alternately, two foam grips facilitate handling in the operative mode. The handle diameter and width accommodates up to the 97.5 percentile of the user population so as to maximize comfort. To extend the cart into the operative mode, the unit is held vertically and lowered with minimal bending effort until the wheels touch ground. Releasing the rear wheel latch allows two castoring wheels to lock out in position to support the main structure at a 65 degree angle to the ground. The front wheels are spherical and allow freedom of movement over terrain that other carts may find difficult. Points of contact between the spheres measures 12 inches and the distance from front to rear wheels is 16 inches.

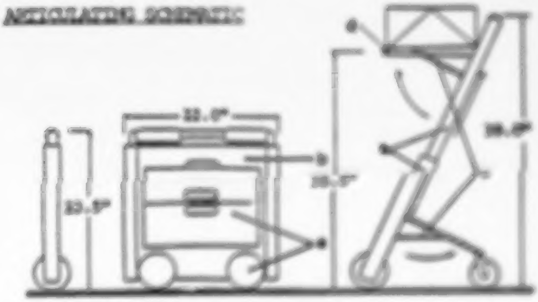
This combination of spacing and castored rear wheels allows maximum handling and turning under heavy loading conditions. Disengaging the handle lock allows for free vertical movement to pull the handle up and lock it out in the fully extended position. This handle height accomodates up to the 97.5 percentile of the user population. Two rectangular support arms guide the handle out of the lower unit and give strength to support and stabilize the handle and tray. Pivoting on a rear axle and supported by two side struts, the tray is guided manually into its set position. A soft handle guides the struts into u-shaped channels which hold the tray in place in a horizontal position. The tray can be inserted in high or low positions depending upon the height of the trunk. The containing unit is removed from the recessed slot in front of the cart unit. Its handle and soft edges allow for ease of access while edges on the tray guide the container to its supported position. The flexible container while in position can collapse or expand to accept varying load sizes up to 30 pounds in weight. Two fully loaded shopping bags fit within the container. The holding walls of the container are tall enough to support its contents but still allow adequate viewing of the goods. After loading is complete, the cart is rolled up to the rear of the owner's vehicle and the trunk lid opened.

The lifting device has a plate that is easily pulled and locked-out to engage the tray of the cart. The cart is positioned so as to mate the tray with the lift plate. At this time the cart is immobile as the load is transferred and the cart disengaged, the container is pushed in the remainder of the way. The container is lowered on the plate by a dual screw drive system. The lift mechanism fits inside the minimum sized trunk and still allows movement through the trunk opening. When the goods are lowered, the plate rests on the trunk floor with the lift mechanism giving support to the bags to prevent spillage. The tray on the cart is released and the handle is lowered back into the unit. The unit is lifted with one hand and the rear wheels are guided back into place flush against the back of the folded up unit. The unit can now be placed in the trunk of the car or in the riding compartment due to its compact form.

PERFORMANCE EVALUATIONS

Raising and lowering the platform in the trunk is accomplished by means of a 12 volt D.C. gear motor. It is powered from the car's electrical system and will have a manual override crank for use when there is a power system failure. The gear motor is connected to a ball screw. A ball screw is a device that changes rotational motion into linear motion with an efficiency of 90%. The ball screw with a lead (linear displacement per revolution) of 0.5 inches raises or lowers the platform in 10 seconds. The platform is guided by 4 vertical linear bearings to allow almost frictionless travel. Maximum current draw will be approximately 1.6 amps.

ARTICULATING SCHEMATIC



The cart is the portable component of the system. It is made of a composite sandwich construction with "S glass" fibers in an epoxy matrix over a foam core for the flat panel portions of the cart and "S glass" composite for the structural components. The weights of the various components are:

a.	struts	1.56 lbs
b.	panels	1.02 lbs
c.	bracing	1.02 lbs
d.	tray	0.78 lbs
e.	wheels and accessory parts	1.00 lbs
	Total weight	5.38 lbs

Based on these weights and assuming a 40 lb load being carried, it would require 1.036 lbs of force to accelerate the cart to 1 mph. in two seconds. The 1 mph. figure is based on a slow walk at the speed of 1.4 ft./sec. To prevent tipping on a sudden stop, the front spherical wheel support mechanism incorporates a horizontal spring. The spring constant was chosen so that during deceleration, the center of gravity does not raise to an unstable position.

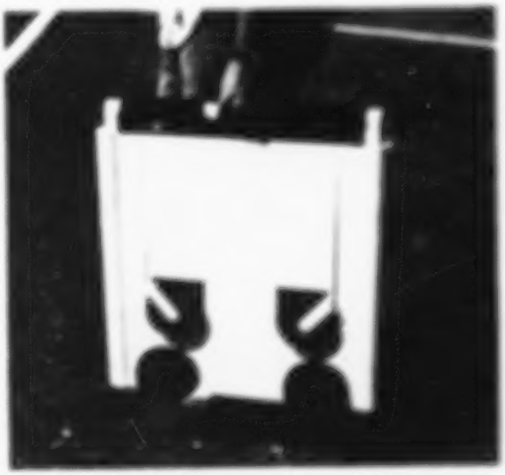


FIGURE 2: Cart collapsed for portability—shows how wheels store flat and unite compactness.

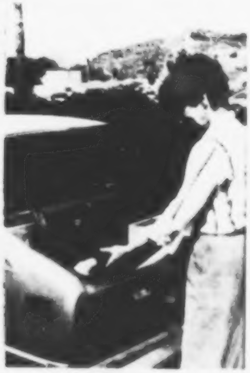


FIGURE A

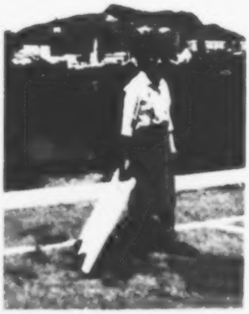


FIGURE B

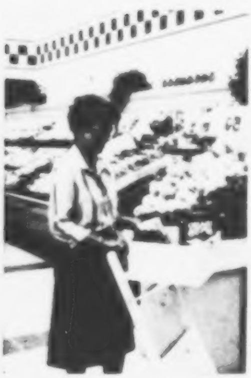


FIGURE C

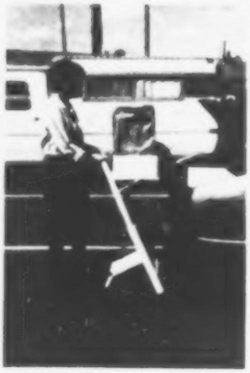


FIGURE D

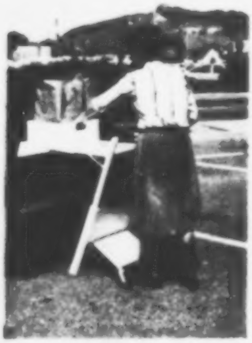


FIGURE E

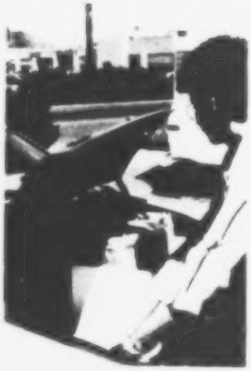


FIGURE F

TASK SCENARIO

FIGURE A: When the cart and lift mechanism is needed, the user removes the collapsed cart unit from its storage place. The figure demonstrates the system contained within the minimum trunk area, larger trunk spaces only enhance accessability.

FIGURE B: Once the cart has been taken from storage, its unique structure allows the user to cary the unit or roll the unit as shown.

FIGURE C: When the cart is ready to be used, the user extends the cart to its operative position. The containing unit is then removed from the front panel and is placed on the cart's tray. Once this has been achieved, the cart is easily utilized and maneuvered throughout the store or the home.

FIGURE D: After the shopping or household task has been completed, the loaded cart is rolled to the automobile. The user opens the trunk and slides out the lift plate to dock with the cart tray.

FIGURE E: When the cart tray and lift plate are properly engaged, the user can now easily transfer the load from the cart to the lift mechanism. This is facilitated by the handle on the containing unit.

FIGURE F: The cart is then disengaged from the lift plate. The load is then lowered into the bottom of the trunk by the lift mechanism's screw jack device. the cart is collapsed into its compact shape and stored for easy accessability to remove the load.

SUMMARY

The cart and lifting mechanism was designed to be an assistive product system primarily focusing on the needs of the physically disabled. The system provides any user with increased independence to safely and easily transfer parcels and goods. Since the cart could conceptually be purchased independent of the lift mechanism, the rang of users would be extended. The unit's esthetic qualities coupled with its unique functional abilities make it a desirable system to any prospective shopper.

ACKNOWLEDGEMENTS

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A MOBILE ASSESSMENT LABORATORY FOR EVALUATING THE DRIVING SKILLS OF DISABLED INDIVIDUALS

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ABSTRACT

A mobile facility has been designed and equipped with the components of a laboratory-based driver assessment system for use by disabled individuals. Its ergonomically planned layout provides wheelchair access to areas for assessment of vision and hearing abilities, reaction time and visual search abilities, range of motion, manual muscle tests, and strength of other functional movements needed for driving. In addition, space is provided for paper-and-pencil assessment tasks and computer controlled tracking with interchangeable steering and control modules. Assessment results obtained in the mobile assessment laboratory (MAL) parallel those obtained with similar equipment in the stationary laboratory.

INTRODUCTION

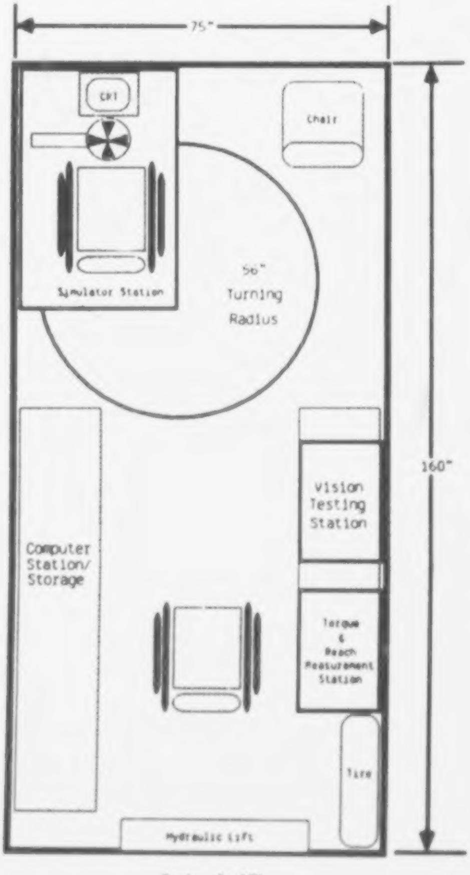
Many former drivers or nondrivers who have either become disabled, or have always been disabled never receive formal evaluation of their capacity for independent driving for a variety of reasons. In many areas there are no driving evaluation professionals with experience in assessing disabled candidates, or the standard assessment and training equipment that is available may be poorly suited to disabled individuals. Disabled individuals often lack the financial resources for transportation to an evaluation center, and are further burdened by the costs of meals and lodging, hiring an aide, or have a relative or friend take time off from work to accompany them. Vocational rehabilitation counselors may lack experience in deciding which candidates should be referred for further driving assessment. The net result is that many disabled individuals who have the capacity for independent driving never get the opportunity to realize that potential.

Figure 1. Mobile Assessment Laboratory (MAL)

BACKGROUND

Basic design of the MAL

A Mobile Assessment Laboratory (MAL), similar to that developed by Wichita State University for work capability assessment, has been developed and evaluated for cost effectiveness and efficiency during the past eighteen months (1). The unit is a Collins "Omni Baron" window van on a Ford 350 chassis with a 138-inch wheel base. It is equipped with power steering, power brakes, air conditioning, automatic transmission, a roof mounted 110-volt air conditioning and heating unit, and a Collins rear mounted hydraulic wheelchair lift. Figure 1 illustrates the external appearance of the completed van. The Omni Baron body and 138-inch wheel base chassis allow a space of 160" X 75" X 74" high behind the driver's seat.



Scale: 1"= 20"

Ergonomic considerations

In order for the screening assessment performed in the van to be valid in comparison with that done in the laboratory, the equipment in the van was laid out as closely as possible (considering space available) to that in the laboratory at the Center. The most notable ergonomic considerations were the wheelchair turning radius and room for the evaluator. Figure 2 illustrates these considerations and shows the lay out of the cabinets, adjustable height table, driving simulator, etc.

METHODS

The purpose of the assessment performed in the MAL is to screen disabled individuals to identify those with the necessary residual abilities required for driving tasks. In order to achieve this purpose the laboratory is equipped with three main components:

1. screening of visual and auditory functions, and evaluation of cognitive, visuoperceptual and psychomotor functions necessary for safe driving;
2. assessment of range of motion, manual muscle strength, and strength of functional movements used in manipulating vehicle controls;
3. assessment of performance on a driving simulator that incorporates most of the component maneuvers encountered in actual driving.

A multiple cutoff procedure is used throughout the evaluation. Clients who exhibit cognitive or perceptual deficits are advised to seek further professional evaluation or remediation as needed. Clients who lack sufficient strength to use modified vehicle controls are advised to seek therapy or further professional evaluation.

Between December 1985 and February 1987 several trips were scheduled for demonstration of the MAL to rehabilitation professionals and for client evaluations. A pilot study demonstrated the efficiency of utilizing a two person team: one person to conduct the assessment and a technical support person to set up the van, make proper arrangements for power, client access, etc. The following locations were visited:

1. Dallas Rehabilitation Institute
   Dallas, Texas
2. Texas Rehabilitation Commission Offices
   Fort Worth and Houston, Texas
3. Our Lady of Lourdes Regional Medical Center
   Lafayette, Louisiana
4. F. Edward Hebert Rehabilitation Center
   New Orleans, Louisiana
5. Mississippi Methodist Rehabilitation Center
   Jackson, Mississippi
6. Regional Office, Division of Vocational Rehabilitation
   Little Rock, Arkansas
7. Division of Vocational Rehabilitation Offices
   Lafayette and New Orleans, Louisiana
8. Southwest Louisiana Independence Center
   Lake Charles, LA

Clients enter the van using the rear mounted wheelchair lift. Audiometric and vision screening tests determine whether they have sufficient visual capacity to drive and whether any audiological deficits need to be taken into account. The MAL is equipped with a Beltone #119 audiometer, a Keystone DVS II Vision Screening Tester , and an American Automobile Association Night Sight Meter for these assessments.

Clients next complete the cognitive component of the assessment. This includes computerized measures of visual reaction and searching abilities, the Motor Free Visual Perception Test, and the Baylor Adult Visual Perception Test (2).

Clients with adequate gross sensory functioning are then evaluated by an occupational therapist for manual muscle strength, range of available motions, and strength associated with available motions. This part of the assessment contributes to the initial prescription of adaptive controls, regarding type of controls and their positioning. Strength and motion assessments involve some of the same controls used later in the driving simulation. A functional strength analyzer is used to gather data regarding the client's ability to apply force for steering and brake/accelerator control functions. This device measures the amount of force applied at various steering wheel positions, steering device positions and brake/accelerator control angles. The force measurements are printed in table form to allow the evaluator to easily compare test results.

The final stage of the assessment is the Tracking Simulator Test (3). The simulator is equipped with interchangeable modular controls that allow clients to be tested actually using assistive devices that may later be prescribed for them. Further adjustments are sometimes made, however. For instance, it may become evident that clients are handling adaptive controls well enough to be considered for simpler, less expensive device configurations than those first tried.

RESULTS

Table 1 illustrates the centers visited, distances from our Center, and numbers of clients assessed. With the MAL located at a site for a full day, up to four clients could be assessed each day, a full screening assessment requiring an average time of one hour forty-five minutes.

Cost data were derived from assessments made at sites in the four states served by the MAL. Based on our experience in actually operating the MAL for 12 months, several assumptions were made in computing cost estimates. For evaluation at remote sites:

1. Travel time estimates based on average speed of 50 mph.
2. Workdays vary from 7 to 9 hours depending on travel time and time available at the site for assessments.
3. Assessment team consists of an occupational therapist and an evaluation technician.
4. Overnight travel for staff requires 2 single rooms at $40.00/night/room.

5. Set up time is under 30 minutes, and assessments average 1.75 hours.
6. Operating costs of the MAL are $25.00/day plus $.30/mile charge to cover actual costs (Louisiana Tech University Motor Pool estimates).
7. Reimbursement to the staff for meals is based on $4.00/breakfast, $5.00/lunch, and $9.00/dinner for each meal away from home.
8. Staff costs, including institutional overhead, are $22.45/hour for the occupational therapist, and $19.00/hour for the evaluation technician.
9. One-half hour of occupational therapist time is allotted for writing a report on each assessment case.

Table 1

Location	Distance from Center	Duration of Visit	Number Clients Assessed
Dallas, TX	250 mi	2 days	Three
Lafayette, LA	200 mi	2 days	Seven
Lafayette, LA	200 mi	3 days	Eight
New Orleans, LA	300 mi	1 day	Two
Jackson, MS	150 mi	1 day	One
Fort Worth, TX	300 mi	1 day	One
Litt. Rock, AR	165 mi	1 day	-0-
Houston, TX	300 mi	1 day	Three
Lake Charles, LA	200 mi	2 days	Nine

Based on the assumption made and considering optimal efficiency of service delivery, cost per assessment ranges between approximately $150 and $350 per assessment. To maximize efficiency it will be necessary to coordinate scheduling of clients at each location to optimally utilize time available for assessment. Rough cost estimates in which the client would travel to the Center and pay for his own travel, lodging, attendant care, and laboratory screening assessment are approximately double the MAL assessment cost.

CONCLUSIONS

Disabled individuals have been evaluated in the MAL during travels throughout a four-state region. Mobile assessment is ideal for disabled individuals who want to drive, but are unable to travel to the stationary laboratory for evaluation. The MAL can make disabled driver evaluation available to people who cannot otherwise obtain such services locally due to the unavailability of professional driver evaluators with the expertise or the equipment needed to perform such specialized assessments.

The MAL also serves an important educational function. As the trained professional staff members take the MAL throughout the region served, rehabilitation counselors can learn which drivers are appropriate for evaluation, and what is involved in conducting disabled driver assessments. This system for bringing assessment to the client offers potential cost savings over having clients come to a Center for evaluation, and has made driver assessment and subsequent licensure a practical reality for many disabled individuals who might never otherwise undergo formal driver evaluation.

ACKNOWLEDGMENTS

Supported by Cooperative Agreement G0083C0097 from the National Institute on Disability and Rehabilitation Research NIDRR, formerly NIHR) of the United States Department of Education, and also by grant funds from the Louisiana Division of Rehabilitation Services.

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COMPUTER PROGRAMS FOR COGNITIVE REHABILITATION: USEFULNESS IN PREDICTING DRIVING SKILLS AMONG DISABLED & NONDISABLED PERSONS

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ABSTRACT

The Computer Programs for Cognitive Rehabilitation (Vol 1) is a set of computerized tasks that are used in assessing and retraining cognitive abilities among brain injured individuals. Two of these, Visual React and Visual Search were used in an assessment battery for predicting driving skill among disabled individuals. This paper describes two studies of potential use of these tests in evaluating a driving candidate.

INTRODUCTION

Each year in the United States between 400,000 and 600,000 persons sustain a traumatic head injury. Of these perhaps 30,000 to 50,000 are left with physical, cognitive and social deficits which preclude their return to former levels of performance. (NIHR, 1986). The majority are males old enough to drive an automobile.

One problem which may result from a traumatic brain injury (TBI) is a visual deficit called unilateral neglect or hemi-imperception. This impairment, a result of damage to the right cerebral hemisphere is seen in 60% of TBI cases. (Friedland and Weinstein, 1977).

Another deficit of TBI clients which impacts on driving performance is visual reaction time (the period of time between perception of a stimulus and motor response). A client with slow visual processing or erroneous responses could be dangerous on the road.

With the development and use of the microcomputer by professionals, assessment of the various perceptual and cognitive deficits began to be computer assisted (Gianutsos, 1981; Bracy, 1983). Advantages of the microcomputer programs include standardization of presentation, on-line storage of results, and potential in training.

Research indicates that perceptual/ cognitive variables are useful in predicting driving performance among disabled and non-disabled persons (Sivak, Olson, Kewman, Won and Henson, 1981). Subsequent studies demonstrated the potential use of computerized video programs in retraining brain injured clients (Sivak, Hill, and Olson, 1983).

BACKGROUND

Two microcomputer programs from the series Computer Programs for Cognitive Rehabilitation (Vol 1) were selected for inclusion in a battery of assessments for predicting driving performance: Visual React and Visual Search (Gianutsos and Klitzer, 1981).

React

In this program, the subject is asked to observe the screen of a microcomputer. The subject is required to stop the "runaway number" (which appears at random on the screen) by depressing any key. The subject is allowed to use both eyes open and free to roam the screen. Sixteen (16) trials are presented. The total time for this

Search

This program requires the subject to search the screen of the microcomputer for a specific shape to match with a target shape which appears in the center of the screen within a box. This program was rewritten for using the Commodore 64, and was simplified from the 8 X 8 to a 6 X 6 (matrix of shapes). Scores are comprised of speed and accuracy.

METHODS

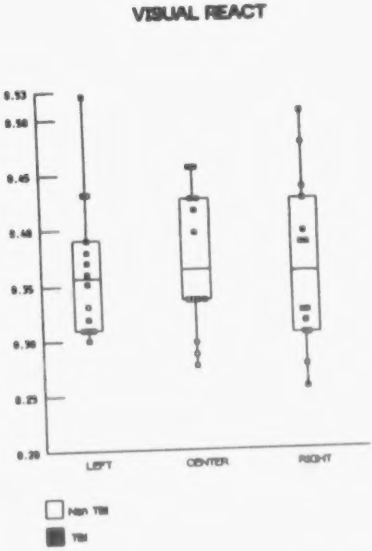
Two experiments were conducted using the tests described above. In the experiment 1 test scores were collected from seven, recovering TBI subjects and from a group of seven non-disabled volunteers. One objective of experiment 1 was to determine if the Commodore version were comparable with the original and able to discriminate between non-disabled and disabled performance.

In experiment 2 a three-group study compared the scores of spinal cord injured (SCI), TBI, and non-disabled volunteers. The group scores were compared with actual driving on an observed, standardized course to determine whether the measures were predictive of driving performance.

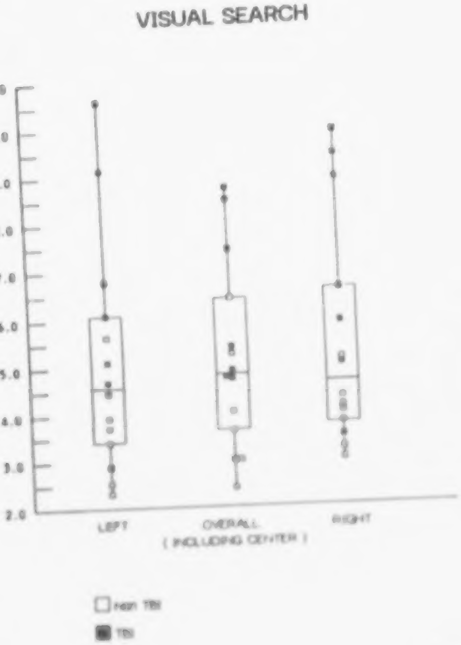
RESULTS

Experiment 1 revealed that Visual React and Visual Search times were longer for the seven TBI subjects than for the seven non-disabled. Statistically significant levels (p=.05) of discrimination between the groups were observed for both measures, with a minimum of overlap between the groups.

This figure shows the Visual React response times of TBI compared to non-disabled. Times are in tenths of a second.



Experiment 2 was a larger study with N=24. Regression analysis found significant, correlations between objective rated driving performance scores in a vehicle and the React test (r=.63, p=.05) and Search task (r=.66, p=.05).



The following table depicts the mean performance by group on the two tasks:

Group	Task	Mean Scores
Able	React	X= 0.32 seconds
	Search	X= 4.09 seconds
SCI	React	X= 0.42 seconds
	Search	X= 5.13 seconds
TBI	React	X= 0.51 seconds
	Search	X= 10.55 seconds

DISCUSSION

It appears from these two experiments that Cognitive Rehabilitation computer programs have value in predicting driving performance. If further study reveals a similar pattern of prediction, these tasks should prove to be a useful addition to the driver assessment battery.

ACKNOWLEDGEMENT

Supported by Cooperative Agreement G0083C0097 from the National Institute on Disability and Rehabilitation Research (NIDRR, formerly NIHR) of the United States Department of Education, and also by grant funds from the Louisiana Division of Vocational Rehabilitation Services.

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PSYCHOMETRIC PREDICTORS OF DRIVING ABILITY AMONG ABLE-BODIED AND DISABLED INDIVIDUALS

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ABSTRACT

Twenty five subjects (7 SCI, 10 TBI, 8 able-bodied) received a battery of psychometric and performance tests. Their ability to drive a full-sized vehicle on the closed course was also evaluated. This study examined the relationship between the psychometric predictors and actual driving ability. Results indicate that the able-bodied subjects drove better than the spinal cord injured subjects, who drove better than the head injured subjects. Excellent inter-rater reliability in evaluating driving performance was obtained, with two raters reaching perfect agreement on 86% of their shared observations. Correlations ranging from .38 to .85 were observed between the predictor variables and the driving criterion. Multiple regression indicated that 81% of the variance in driving could be accounted for by two composite predictors, and knowledge of group membership added nothing to the predictive accuracy. These results offer promise toward developing a simple screening battery for identifying client's who can progress directly to in-vehicle assessment.

INTRODUCTION

There is growing interest in the professional use of cognitive and perceptual testing for disabled driver. This objective approach is recommended over procedures in which subjective judgement is used to decide whether a person has sufficient cognitive and perceptual skills. Disabled drivers without valid assessments may have dangerous deficits which could go unnoticed until the client is on the road.

The use of validated testing procedures can assist in training disabled clients. Specific areas of needed improvement may be observed, thereby providing training objectives. Research conducted at the University of Michigan Transportation Research Institute has shown the value of their approach (1,5).

The initial study (1) used psychological tests to predict the driving skills among 23 brain injured, 8 spinal cord injured, and 10 able-bodied individuals. Subjects were assessed on psychometric tasks including the Wechsler Adult Intelligence Scale (6); driving was assessed on closed course, and then on the public thoroughfares. They observed that different tests predicted the performance of the groups, but that the Picture Completion subtest of the WAIS had the highest correlation (r=0.72) with driving performance. A pilot intervention (2) to promote improved driving performance by training 4 brain injured clients to complete paper and pencil perceptual tasks was conducted. Two other brain injured clients viewed driver education filmstrips as a control intervention. While the experimental training group improved more than controls on the battery of predictive tests, both groups improved comparably in their driving performance. Subsequent research has supported the efficiency of perceptual training in improving driving performance (3), and also suggests that computerized video tasks may be a useful medium for perceptual training (4).

Other researchers have demonstrated the usefulness of psychometric variables in predicting driving skills among the disabled. For example, visual reaction time has been shown to be significant predictor of driving skill in two different studies (7,8). In a separate investigation, 79% of the variance in measured driving performances of N=28 head injured clients could be accounted for by the following cluster of five predictors: night vision, depth perception, auditory reaction time, and the Arithmetic and Digit Symbol subtests from the WAIS-R (9). This latter study is flawed by the relatively large number of steps in the regression calculation and the relatively few number of subjects; this condition can substantially inflate the estimated degree of relationship among the variables (10). In the present case, this 79% estimate can be corrected for shrinkage (11); using this corrected estimate, the five variables still account for 76% of the variance in driving performance.

These studies indicate that a variety of psychometric measures may be used to predict driving skills among disabled persons who are seeking drivers licenses. The present study examines the relationships between a set of psychometric predictors used in driver evaluations at our Center and actual driving performance.

METHOD

Subjects

Twenty-five subjects completed all of the measures used in this study. There were 10 head injured persons, with a mean age of 29.3 years. Eight of these were right handed and, 7 of them were male. All had sustained severe traumatic brain injuries (TBI), and had completed all formal rehabilitation. Seven subjects were in the spinal cord injured (SCI) group; their mean age was 26.7 years, 6 were right handed and 6 were male. All had sustained traumatic spinal cord injury except for one client whose paraplegia was due to a congenital spina bifida. About half of the SCI group had injuries at a sufficiently high vertebral level to cause some degree of quadriplegia. All SCI subjects had completed formal rehabilitation as well. In recruiting volunteers for the TBI and SCI groups, referring agencies were instructed to invite only those candidates they regarded as potential drivers to participate. Thus, the disabled groups were fairly representative of the sort of disabled clients who might be referred, or who might refer themselves for driver evaluation. The able-bodied group was 8 subjects who were recruited from an introductory psychology class at Louisiana Tech University. Their mean age was 18.8 years, 7 were right handed, and 3 were male. All subjects were evaluated without charge, and all received feedback about their performance and recommendations regarding their potential for independent driving.

Evaluation measures

The psychometric predictors used in the present study included the following 5 subtests of the WAIS (6): Picture Arrangement, Block Design, Digit Symbol, Arithmetic, and Picture Completion. These measures were collapsed into two lumped variables based on whether there was a motor component required to respond to the task. This yielded a motor-dependent measure (MOTWAIS) composed of the former 3 subtests, and a motor-free measure (NONMOTOR) composed of the latter two.

Subjects also received the Motor Free Visual Perception Test (MFVPT, 12) and the Baylor Adult Visual Perception Test (13). These two test examine different aspects of visual perceptual functioning using motor-free (12) and motor-dependent (13) response formats. Each yields a set of subscale scores and a composite score reflecting overall performance.

The Trail Making Test, parts A and B, from the Halstead Reitan Battery (14) and the Symbol Digit Modalities Test (15) were used as measures of information processing speed and efficiency. The Trails A subtest required subjects to connect a series of numbered dots in sequence and the Trails B subtest required numbered and lettered dots to be connected in alternating sequence (eg. 1-A-2B-3...). The Symbol Digit test is the converse of the WAIS Digit Symbol; subjects see a translation code of numerals 0 through 9 associated with different geometric marks, and they must identify the numbers that correspond with a long series of these marks that appear on the response page. On the WAIS Digit Symbol, the subject sees a similar translation code, but has to write the marks that go with the numbers indicated on the response sheet. The advantage of the Symbol Digit test is that is can be completed in a non-motor format by naming the numbers that go with each of the marks in series, and thus is more pure as a test of cognitive function for quadraplegics.

The final predictive measure was the Driver Performance Test (DPT, 16). This measure assesses knowledge of how to respond in a series of videotaped scenes of potentially dangerous driving situations. Separate scales assess capacity for searching the scene, identifying relevant stimuli predicting what is likely to happen in the scene, deciding what to do to avoid danger, and executing the correct maneuver. A composite score is also computed. Although the DPT is presented as a test of knowledge and judgement, the fast pace of its automated presentation makes it a very challenging and demanding test to complete. In many regards, the DPT appears to measure capacity for polysensory information processing, integration, and motoric output, as well as the component skills identified by each subscale. The DPT subscales collapse to form an overall composite score as well.

The criterion measure involved expert ratings of performance in driving an appropriately modified full-sized vehicle about a closed course. Eight specific maneuvers were evaluated, these were starting and stopping, left turn from stop, right turn from stop, left turn while slowing, right turn while slowing, slalom navigation at 10 mph, slalom navigation at 15 mph, and performance on an evasive maneuver in which the subject was given only several seconds to veer left, veer right or stop. Two raters independently rated these maneuvers for 8 disabled subjects; perfect agreement was reached on 86% of the observations. The primary rater also rated performance on parameters of following directions, tracking, braking, accelerating, and appropriate speed control.

Procedure

Disabled subjects were individually evaluated at Our Lady of Lourds Hospital in Lafayette, LA, at the Independent Living Center in Lake Charles, LA or at our Center in Ruston, LA. Closed course driving ranges were prepared at the Lafayette and Ruston sites, the Lake Charles clients traveled to Ruston for completion of the driving component of the assessment. All able-bodied subjects were evaluated at the Ruston site. An overview of the procedure is shown in the following figure.

Initial screening involved completion of medical and driving history forms and interviews, as well as objective evaluation of mental status (17). In the pre-assessment, sensory-motor component, clients received evaluation of vision and hearing functions, range of motion, muscle strength, and assessment to identify the presence of hemispatial visual neglect. The cognitive processing component involved completing the assessment measures described in the preceding section, as well as the Reaction Time Measure of Visual Fields and Searching for Shapes subtests from the Computer Programs for Cognitive Rehabilitation (18). The knowledge component involved administration of the Driver Performance Test in a group format.

Subjects then completed evaluation on the Louisiana Tech Tracking Simulator (19) prior to advancing to driving the Small-Scale Vehicle (20) on a closed course. The final assessment component involved driving the full-sized vehicle on a closed course.

RESULTS AND DISCUSSION

There were clear and significant differences between the groups in terms of their driving performance. With a score of 100 being perfect performance, the mean performance of the able-bodied subjects was a 94.7, for the SCI subjects it was 83.6, and for the TBI it was 66.4. All of the psychometric measures except the MFVPT correlated significantly with driving performance, and these correlations exceeded the .005

alpha level. Correlations between each measure and the criterion are shown below:

MOTWAIS	.807	NOMOTOR	.706
SYM-DIG (W)	.782	SYM-DIG (O)	.839
TRAILS	.668	MFVPT	-.382
BAYLOR	.632	DPT	.847

Multiple regression analysis using only 2 predictors, the DPT and the NOMOTOR WAIS variables yielded an R-Square coefficient of association of 0.81, which indicates that 81% of the variance in driving performance could be accounted for by these two predictors alone. Even when corrected for shrinkage (11), the adjusted R-Square remains an impressive 0.79. Including knowledge of group membership in the regression equation made no significant addition to the level of prediction.

These results hold promise toward the development of standardized assessment procedures for disabled clients who are seeking driver training or licensing. With further refinement, it may be possible to identify a brief screening exam to identify clients who need no further assessment before proceeding to a road test, and also to identify and validate a set of procedures to use in further evaluation of those clients who should not proceed directly to evaluation on-the-road.

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WALLY'S TROLLEY

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ABSTRACT

Accessibility to private residences poses a very real problem in extremely hilly cities like Pittsburgh. Wally's Trolley is an individual passenger cable car designed to transport a person with limited mobility up and down a slope. It was designed for use at the senior author's residence when his wife's arthritis limited her ability to walk. It permits the user to transfer from the flat surface of the back porch to the cable car and transfer again to a flat surface at the street level. The entire system was designed to be constructed of materials easily available from local sources and at a reasonable cost. Construction of the cable car system has permitted an individual with limited mobility to continue to reside in a home with grades beyond her ability to negotiate.

INTRODUCTION

In cities with rough terrain a very limited number of accessible homes are available. Many individuals who become disabled are reluctant to relocate for financial or personal reasons. They often lose their remaining independence because they cannot get to and from the house. Taking a cue from the public transportation incline or cable car systems in the local city, the senior author designed a private system and constructed it in a yard with an average grade of 20 percent.

MATERIALS AND METHODS

Cable car

The car was constructed with two seats in order to permit the rider to face the direction of travel and allow space for transport of materials on the unused seat. One side was left open for easy transfer in and out. A platform was constructed at the street level for easy transfer to and from the cable car. See Figure 1. At the house level a drawbridge was built to span the distance from the track to the porch. This permitted the sidewalk to remain functional for foot traffic. See Figure 2. The car, platforms, drawbridge, and tracks were all constructed of weatherproof, preservative treated, lumber.

The car travel is controlled with a momentary telephone switchboard type lever switch. The center position is off and car movement is in the direction the switch pressed.

The wheels were constructed of two different sized disks forming a smaller wheel with a flange. Each wheel was equipped with slack cable brakes for safety.

Figure 1. Street Level Platform

Counterbalance cart

The public incline system that served as an inspiration for this project uses a second passenger car as a counterbalance for efficiency, however only one car was needed for this private system. The counterbalance was achieved by constructing a smaller, brick filled cart that rode on its own track. This smaller cart was designed low enough to pass under the passenger car and sufficiently narrow to move between the wheel flanges. See Figure 3. This smaller cart was equipped with a cable guide and a system for self oiling the cables as they pass over it.

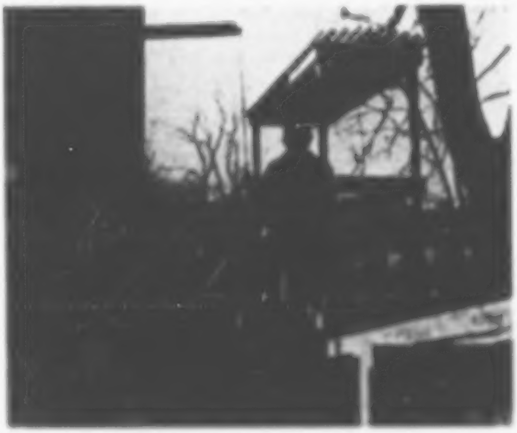

Figure 2. Drawbridge

Track

The track spans a distance of 105 feet and was built in 16 foot sections or units for easy

Figure 3. Cable Car and Counterbalance

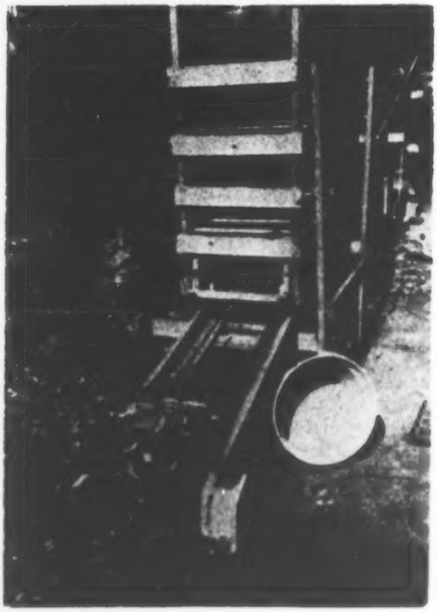

Figure 4. Gearmotor, cover removed

assembly and dismantling should repairs become necessary at any time. The outer rails were constructed of treated wood 2x4s on edge upon which the passenger car wheels rode. A lower inner track was attached to the outer rails to accommodate the brick cart.

Drive system
The system is operated by a 1/4 HP gearmotor mounted at the lower end of the track near the house. See Figure 4. Power is provided by the household current. The electricity for the system is turned off from a main switch in the house when the system is not in use.

RESULTS

The system has been operational for 8 months with no major breakdowns. It has permitted the resident with disabilities to leave the house on her own on a regular basis. She has been mobile on flat surfaces for longer periods during each day which the physician attributes to the reduction of strain on the knees due to climbing. As a result the move to a residence with a flat yard was avoided.

CONCLUSIONS

Some of the old solutions to public transportation in hilly terrain can be applied to the problems of mobility for individuals with disabilities in a private setting. People whose conditions are exacerbated by walking, even when aided, up and down grades can remain independent and functional for longer periods of time if those barriers are surmounted.

Please direct any questions about this project to the authors at:

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A SMALL-SCALE VEHICLE FOR ASSESSING AND TRAINING DRIVING SKILLS AMONG THE DISABLED

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ABSTRACT

A Small-Scale Vehicle (SSV) was developed for the purpose of assessing and training skills of disabled individuals who wish to become licensed to drive. The SSV is an electric golf car that has been modified to accept various types of adaptive driving controls. This vehicle allows the driving evaluator the opportunity to evaluate the client's performance in a dynamic situation. It allows the potential driver the opportunity to practice basic vehicle maneuvers in a safe, low-anxiety environment.

DESCRIPTION

The Small-Scale Vehicle is a Club Car electric model golf car that has been modified to accept various types of adaptive driving controls. The cart's major systems have been changed to allow for the greatest possible flexibility in configuring the vehicle for use by persons with disabilities.

Steering system

The steering system includes a commercially available adjustable steering column that allows the steering wheel to be positioned to suit the needs of the client. The system will accept various steering wheel types and sizes. Any standard adaptive steering device may be used. Steering effort is reduced by the use of a hydraulic power steering system driven by an electric motor mounted at the back of the SSV.

Brake/accelerator system

The standard golf car brake and accelerator systems have been replaced with electrically modulated systems. The brake/accelerator functions are performed with the use of electronic modules, which are models of commercially available adaptive driving controls. Modules have been built to imitate the motions and effort required to operate push-pull hand controls, push-right angle hand controls, servo-assisted push-pull and side to side controls. In addition, commercially available floor mounted push-pull and foot steering controls may be used. The standard brake and accelerator pedals are also operative for use by those who have sufficient lower extremity functioning. An independent auxiliary braking system has been added for use by the evaluator.

Seating

The standard golf car seats have been replaced with high-back automobile bucket seats. Lap belts, chest restraints and armrests have been added to provide for the lateral stability and safety of the client and evaluator.

Safety features

In addition to those items previously mentioned, a roll bar, warning lights and buzzers, a fire extinguisher, circuit breakers, and a multi-step start up sequence have been added to enhance client and evaluator safety.

DISCUSSION

As the Small-Scale Vehicle has been used in the driver assessment education and training program at the Center, many advantages have been become evident. These include:

Variety of control options

The SSV can be configured with all of the major types of control systems available for use in motor vehicles. This gives the evaluator the opportunity to determine the most appropriate system for the client.

Dynamic experience

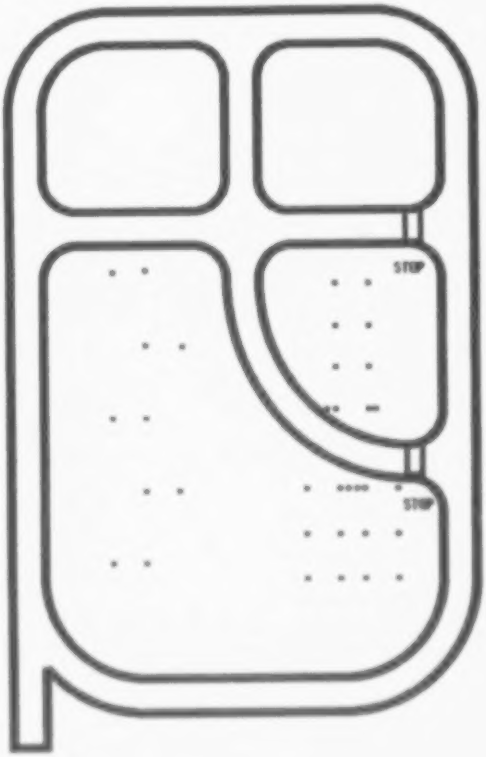
The evaluator is able to determine the effects of vehicle dynamics on the stability of the client as he or she moves the vehicle about the driving course. The evaluator is also able to objectively compare client performance in using different types of adaptive control systems. Performance data is collected on the client's ability to perform starting/stopping, turning, serpentine and evasive maneuvers. This information is valuable in determining the most appropriate adaptive control system for the client.

Safe, controlled environment

The SSV is driven on a closed course, without the hazard and distraction of other motor vehicles. This type of driving environment also reduces the anxiety level of the clients, many of whom were injured in traffic crashes and are apprehensive about resuming their driving activities.

Relatively low cost

The SSV can provide a lower-cost alternative to the number of full-size vehicles that would be required to provide the same evaluation capability. It is estimated that a suitably equipped SSV will cost about one-half of a comprehensively equipped full-size vehicle, such as a van. The spaces required to store and to operate the Small-Scale Vehicle are considerably less than those required for full-size vehicles. The SSV driving range overall dimensions are 100 X 200 feet with only about one-fourth the area of a comparable full-size range.



Carryover to training

As clients are learning to operate the adaptive driving controls of the SSV, they are acquiring skills that will be transferred to their own full-size vehicles. This will help reduce the amount of instructional time required to orient the client to his newly adapted vehicle. For those clients who are not yet acceptable candidates for driving, the SSV offers the opportunity for practice time in a controlled environment.

The Center anticipates that the factors of low cost, flexibility, and reduced training time will be seen as advantages by other training centers throughout the country. The use of such vehicles at other sites may also lead to the development of improved standards for driver assessment and training for the disabled.

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DEVELOPMENT OF A COMPACT LIFT AND TRANSFER DEVICE

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ABSTRACT

A portable lifting machine has been developed for moving quadraplegics without sling insertion under the buttocks, while maintaining dignity and preventing undesired rotation or jack-knifing of the body, as can occur with traditional lifters. The device is especially helpful in the transfer of spastic quadraplegics; the subject is lifted to a semi-standing position with upper back and thigh slings while braced against knee and foot supports. The device folds easily for storage without disassembly.

INTRODUCTION

Traditional patient lifters composed of a base, upright, and overhead boom have limitations in the transfer of high level spastic quadraplegics. Specifically, the insertion of a sling under the subject can result in spastic leg extension which must be corrected before the transfer proceeds. Once the sling is attached to the overhead boom and lifting begins, spastic leg extension may again be triggered, upsetting the subject's balance and causing unwanted pitching and rotation. With one or both legs extended, accidental contact with the lifting machine is probable, placing an additional burden on the attendant.

BACKGROUND

A more controlled and less demanding means for an attendant to transfer a spastic quadraplegic was needed, and our design goal was to develop a simple attendant operated device which could be discretely stored when not in use.

The preferred method of transfer at the project's inception was the bodily lifting and pivoting of the quadraplegic subject by his attendant. This method was favored because no equipment was needed and the attendant was able to control spastic leg extensions by locking the subject's legs and knees between his own, locking his arms under the arms and around the back of the subject, and then lifting and pivoting him to a new position. This method proved much quicker and more comfortable for the subject than the use of conventional lifting machines, but employment of an extremely able-bodied, willing, and competent attendant was required.

Full sized overhead sling lifters had been tried and were unacceptable in this situation because of the problems of sling insertion and rotation during lifting, and because of the bulk and obvious presence of such a device in a small apartment. Portable sling lifters were also unacceptable because of the close proximity of the lifting boom to the subject's face, with the likelihood of accidental contact. Separate knee and underarm slings helped to reduce leg spasms by supporting the subject in a fetal position, but were rejected because of the discomfort and lack of dignity in lifting by this method. Slingless transfer devices where the subject is pulled forward onto a wheeled stand were also rejected because of the lack of dignity in transfer.

METHOD

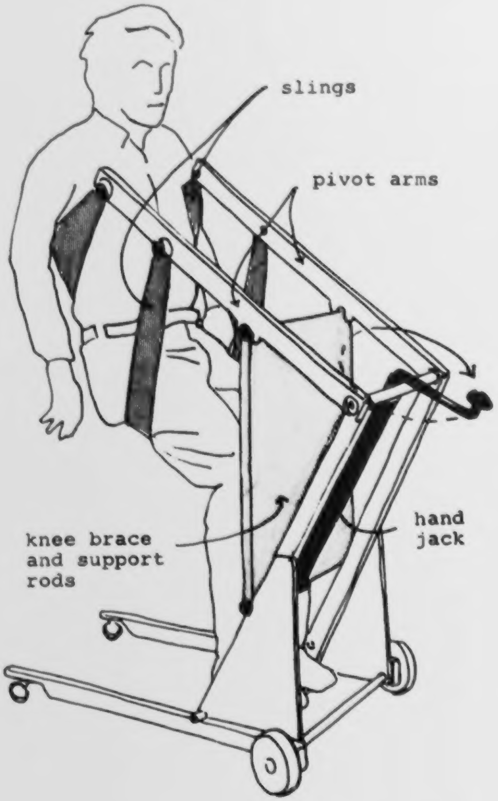
Design development has centered on mimicing the dynamics of an attendant-performed lift and pivot transfer by means of an attendant operated compact mechanical device consisting of a wheeled base with two parallel uprights and pivot arms. A semi-rigid upper back sling and a flexible thigh sling are suspended between the two pivot arms and are removeable. A knee brace and foot rest are fixed between the uprights, and the pivot arms are moved through an arc by a hand operated jack.

The subject is held in a seated position on the side of the bed while the back support is attached under his arms to the ends of the pivot arms. The back support is nylon webbing and fabric with a flexible plastic insert which keeps it from bunching up under the arms and spreads the load evenly over the back. The thigh support is a webbed nylon strap. Both are adjustable for length and fitted with metal rings at their ends, which attach to pegs on the pivot arms. The knees and feet are braced against the central pad and footrest, and the pivot arms are raised, lifting the subject to a semi-standing position on the wheeled base. The thighs move through an arc parallel with the pivot arms, and the lower legs and back remain perpendicular to the base. So suspended, the subject is moved to the new transfer position and lowered back to a seated position. The back and thigh slings are then removed.

The device is folded for storage by lifting the pivot arms up off of their support rods, pivoting the rods back against the uprights, and then dropping the pivot arms against the uprights. The legs of the base can also be rotated up by releasing two locking pins. Folded, the device is 24" x 36" x 8" and can be stored in a closet.

RESULTS

The prototype machine is used daily by an attendant otherwise unable to lift the 180 lb. subject. The device supports the subject as intended and inhibits spastic leg extension during transfer. The slings do not apply pressure under the arms, can be inserted and removed easily while the subject is seated, and leave the buttocks unencumbered for toileting.



Design Mobility Inc. patent pending

CONCLUSIONS

This method of transfer is preferable over a conventional lifter for the subject spastic quadraplegic, and is an acceptable substitute for bodily lift and pivot transfers executed by an attendant. Testing and evaluation of the device is invited to determine its suitability for a larger population. Further development is planned to facilitate automobile transfer and to allow supported standing for theraputic purpose.

ACKNOWLEDGEMENTS

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DRIVING TASK EVALUATION AND TRAINING VEHICLE FOR THE DISABLED: SMALL-SCALE VEHICLE

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ABSTRACT

One of the tools for assessment and training of disabled drivers being developed at the Center is the Small Scale Vehicle (SSV). The SSV is a common golf car that has been outfitted with power steering, improved seating, automotive type foot pedals and modular accelerator/brake controls. The steering system can accept several different sizes of steering wheels which can be placed in many different positions. Accelerator/brake control is accomplished through device simulator modules (DSM) which are electronic accelerator/brake controls physically configured to simulate an assistive driving devices. All controls are easily reconfigured so that the SSV can be fitted to a client quickly. The Center's first SSV has been used to evaluate about 50 clients and has proved useful as a tool for developing a driving device prescription. This paper examines the design and technical aspects of the SSV. Engineering criteria, trade offs, and design philosophy are discussed.

INTRODUCTION

Potential driver training hazards

Assessing and training unskilled drivers in an "on road" environment have many potential hazards. The demands of these activities coupled with learning to use a disabled body and an unfamiliar control system can be very difficult (1,2,4). A major problem with using full-size-vehicles for driver assessment is that it is difficult and expensive to configure them with several control systems (1,4).

SSV concept

The Small-Scale-Vehicle was designed to address the problems of driver training hazards and control system assessment. The concept is to provide a vehicle which operates more or less like a small car with modular controls that mimic typical assistive driving devices.

DESIGN REQUIREMENTS

In order to assess design trade offs, the ideal SSV must be defined. The following are requirements for an ideal SSV.

Steering

1. Steering column would be adjustable such that it could accommodate many lengths and angular positions (1,4)
2. Steering system would accept several sizes of steering wheels (1,4).
3. Steering system would accept right angle and horizontal steering system (1,4).
4. Steering system would have about 3 1/2 steering wheel turns lock to lock (5).
5. Steering system could be put in a one wheel turn lock to lock mode (1).
6. The number of steering wheel turns from center to lock, for left and right should be symmetrical. There should be no angular procession of a given point on the steering wheel.
7. Steering backforce should be adjustable to 3 levels, approximately 22 oz, 10 oz and 4 oz at the rim of the wheel. The driver should experience "road feel" (1,4).
8. Steering system should be able to move from lock to lock in 2 seconds and respond to a 0.2 second steering reversal.
9. Steering system should be efficient as possible.
10. Steering should remain functional in the event of loss of power assist (1).

Brakes

1. Brake system must stop or slow the SSV with a force proportional to the force applied to the current braking control (i.e., brake pedal, hand control, etc.).
2. Brakes must move to full on within 1 second of a full on actuation of the brake control.
3. Brakes must be controllable from all assistive driving devices.

Accelerator

1. Accelerator system must operate linearly from stop to full throttle with no jumps (1,4).
2. Acceleration must be proportional to the position of the current acceleration control (i.e., accelerator pedal, hand control, etc.).
3. Full-throttle acceleration from a dead stop must be such that occupants are not injured (3,6).
4. Accelerator system must be fail safe. In other words, it must not fail to the full throttle setting (3).

Seating

The seating system on the SSV should consist of automotive type seats for reasons of safety, positioning and similarity to a full-size vehicle (1,2,4). Highback bucket seats should be selected. This type of seat combined with a lap belt and chest belt results in a safe seating combination for the client (1). The seat should have an adjustable back and adjustable front to back position just as in most full size vehicle seats.

Aesthetics

Every attempt should be made to keep the overall appearance of the SSV like that of a golf car or small automobile. In doing this the SSV will be more inviting than intimidating (1).

Controls

Every attempt should be made to keep the driving trainer controls as simple as possible. Operation must be straight forward and as close as possible to the operation of an automobile (1).

Safety

Because most people trained on the SSV will be disabled, and most will not be able to evacuate the vehicle under their own power, safety is of utmost importance. The SSV should have the following safety features:

1. Structural Integrity - The SSV should be built such that it will not come apart under normal use. It should be built to operate in any situation a normal golf car would be used (3).
2. The SSV should meet or exceed all American National Standards Institute (ANSI) standards pertaining to golf cars (3,6).
3. All electrical systems should be fused such that there is no reasonable possibility of battery explosion, wires melting or component fires.
4. Seat belts should be provided for driver and instructor (1,4).
5. An instructors brake should be provided. This brake should override all systems and provide positive stopping capability (1,4).
6. A roll bar should be provided. This roll bar must be able to support the entire weight of the SSV (1,4).
7. A method must be provided to lock the SSV in the off position to prevent use by unauthorized persons.

IMPLEMENTATION

Description of SSV1

As with all prototype machines, development of the first SSV (SSV1) was a learning experience. After consideration of several approaches, it was decided to use a golf car for SSV1 development. This approach makes use of a commercially available vehicle with many desirable features. SSV1 is a converted Club Car model DS electric golf car. (See photograph 1)

Steering. SSV1 was fitted with linkage type Ford power steering. The steering spool valves were rebuilt to reduce the effort required to steer the vehicle. Hydraulic power is provided by a standard power steering pump driven by a 36 volt, 2hp electric motor. The electric motor is controlled by an open-loop pulse-width modulator designed at the Center.

Brakes. The brakes on SSV1 are a modified magnetic trailer brake controlled by an open-loop pulse-width-modulator. The brakes are activated by a 5 volt analog signal.

Accelerator. The mechanical drive train and the 36 volt, 2hp electric motor of the golf car were retained without modification. The resistive speed control was replaced with an open-loop pulse-width modulator. The speed of the SSV1 is controlled by a 5-volt analog signal.

Assistive driving devices. In order to achieve the goal of being able to quickly change driving devices, we elected to build device simulator modules (DSM) (see photograph 2). Although mechanical controls have the advantage of being "off the shelf" items, mounting of several mechanical controls could clutter the SSV and reduce leg room for the client. The use of DSM's does not preclude the use of mechanical controls, DSM's simply make evaluation with servo type controls and some type of hand controls easier and more aesthetic.

A DSM is an electro-mechanical module that physically functions as a particular given driving device (i.e., provides the same motions and forces). The DSM is instrumented with electronics to provide necessary signals to the accelerator and brake systems. In many cases, a given DSM can simulate several types of driving devices. To insure interchangability, all DSM's used by the Center conform to an electrical signal standard that is used by the two computer aided driver assessment systems.

Lessons learned from SSV1

The biggest lesson learned from SSV1 is not to underestimate the task of modifying a golf car to become a handicapped research vehicle. Other important lessons were the following:

1. Use as much "off the shelf" technology as possible.
2. Modify the golf car as little as possible.
3. Use as much of the original golf car braking system as possible.
4. Aesthetics and ease of use are very important.
5. Proper documentation is extremely important.
6. Rainproofing is necessary.

Description of SSV2

SSV2 in form, fit and function will do the same job as SSV1. However, SSV2 will be built using the lessons learned from SSV1. SSV2 will use the same DSM standard as SSV1 thus maintaining compatibility with other Center equipment.

SSV2 will use hydrostatic steering. Hydrostatic steering offers several advantages:

1. Physically easier to mount.
2. SSV can still be steered with power off.
3. Greater freedom in steering parameters.

The brakes will be activated by an electric linear actuator. Speed control will use an "off-the-shelf" fork lift motor control. Standard automotive seats will be used. Every attempt will be made to keep the appearance neat and trim and to have SSV2 operate like an automobile.
Utmost attention will be given to safety. In the event of a system malfunction or a non-standard event the drive motor speed control is shut off automatically.

CONCLUSION

The Center has successfully defined the requirements for an SSV and has developed SSV1, which has proven to be a reliable prototype of the SSV concept. SSV1 has been used to assess the driving capabilities of about 50 clients. SSV2 is currently under construction and is expected to be operational in May 1987.

Future of SSV's

Future development of the SSV concept could follow 2 paths - evaluation/research vehicle and personal vehicle for the disabled.

One extension of the SSV concept that could benefit both research and personal vehicle needs would be to lengthen the frame such that the SSV could accommodate a wheelchair. The extended frame SSV could be used for assessment of equipment positioning in a modified van, as well as providing the technology for a vehicle that a handicapped person could use to get around the neighborhood (7).

Other possible modifications for an evaluation/research vehicle are the following:

1. Addition of torque sensor in the steering column thus allowing an exact, dynamic reading of steering efforts.
2. Independent control of each wheel brake and a system by which the driver trainer can introduce a disturbance to the steering system. This would allow the simulation of component failures.
3. Addition of electronics that would allow driving parameters of the SSV to be changed during the assessment. This would allow the SSV to simulate several types of vehicles (i.e., heavy vans, light sports cars, etc.).

ACKNOWLEDGEMENTS

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Special Interest Group 3

Augmentative and Alternative Communication

Chair: Craig W. Heckathorne

Collaboration - An Essential Issue in the Development of Augmentative Communication Devices

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ABSTRACT

As a first step in establishing open channels of communication between clinical and technical personnel, the Augmentative Communication Service (ACS) and the Rehabilitation Engineering Department (RED) at the Hugh MacMillan Medical Centre in Toronto, Canada have formed a committee whose principal goal is to support research and development activities and to provide technical solutions to clinical problems encountered in the delivery of services to nonspeaking children and young adults.

This paper discusses a model for establishing open communication between clinical and technical personnel and outlines the various phases involved in the development process, some of the problems encountered, as well as some of the critical issues which have become apparent from this collaborative effort.

INTRODUCTION

Technological advances in the field of augmentative communication have led to an ever-increasing array of commercially available technical aids for augmenting the communication of nonspeaking individuals. In some cases, these aids have truly met the needs of the individuals in question and have facilitated more effective and efficient communication. In other cases, the aids have fallen short in addressing the communication needs of nonspeaking individuals; as a result, they have limited clinical application and are often abandoned on clinic shelves. Shortcomings in technical aids often result when technical applications are led by the technology itself rather than by clinically defined needs. Such developments frequently result in an inefficient use of human and financial resources, in addition to frustrated users and clinicians.

Until recently, clinical personnel have generally taken a backseat in the area of technical development. There is an obvious need for active collaboration between clinicians in the field and rehabilitation device designers to ensure that clinical problems, which require technical solutions are clearly defined, and that research and development activities are directed towards solving those problems which are considered priorities in the field.

A joint committee drawn from staff of the ACS and the RED of the Hugh MacMillan Medical Centre was initiated in 1983, the goal of this committee is to support research and development activities and to provide technical solutions to clinical problems encountered in the delivery of services to nonspeaking children and young adults. The committee continues to meet on a regular basis to identify, develop and evaluate projects, and to participate in technology transfer with industry when appropriate. The committee is comprised of personnel from RED who bring expertise in the areas of mechanical engineering, electronic technology, and industrial design. The personnel from ACS are clinicians and researchers with expertise in augmentative communication and accessing. Additional personnel are recruited from ACS, RED and other Centre departments as required.

THE DEVELOPMENT PROCESS

The development process as identified by the committee, involves the following six phases: identification of a clinical need; suggestions of potential technological directions; conceptual/prototype development; project planning; development and evaluation; and commercial production. Each of these phases is discussed in more detail below.

1. In the first phase in development, the clinicians on the team identify a critical clinical need(s) and sets priorities. These identified need(s) arise from review and analysis of current research and approaches to solving the identified problems combined with a review of existing technological aids. A general requirements statement, developed by both clinical and technical personnel, emerges and is then addressed.

2. In the second phase the team (both technical and clinical) discuss the clinical need in greater detail. Specific examples of clients demonstrating the identified problem are presented. At this time generic requirements are investigated in detail to assure the entire team understands the clinical problems being raised.

3. In the third phase preliminary ideas regarding possible solutions are discussed until a major direction emerges. A primary team composed of key members from the committee is identified to more fully develop the concept. As the technical options develop, clinical implications are considered and weighed, and appropriate clinical/technical compromises are negotiated. To assist in the formulation of general design requirements, the technical members of the team are often called upon to construct simple, models of various design options. Upon demonstrating the features and operation of the models at the committee meetings, refinements are made based on discussions and recommendations of the group. Decision making at this stage is critical. The team must adopt a realistic view so that technical solutions can be implemented. Clinical input is important at every decision point since slight variations which are technically insignificant may have major clinical impact.

4. Once a promising technical solution is achieved, either as a concept or in prototype form, and is accepted by the committee, the need for external funding for ongoing development is evaluated. Committee members experienced in the grant writing and funding process are called upon to locate possible funding sources and to investigate

submission timelines and criteria. In some cases, funds may be secured internally for development of small projects.

5. Upon receipt of necessary funds, further prototype development occurs. Even at the prototype stage, clinical input is ongoing to assure that basic considerations such as safety and environmental factors are considered along with the preliminary evaluation of technical feasibility and reliability. During this fifth phase, clinical and technical field evaluations are conducted with appropriate clients to ascertain the following: clinical effectiveness, technical reliability and acceptability to the client. In the event that results of stage 5 indicate a need for further modifications, a second round in the development phase may be undertaken.

6. The sixth phase varies with the outcome of the preceding phase. If results warrant it, the sixth phase may involve seeking out an appropriate manufacturer to construct, market and support the product.

PROJECTS

Several of the projects undertaken through this process are at different points in the development phase. Specifically the team developed one of the original commercially available latching switches[1]. This developed from a clinical need to provide two prime functions: one being a motivating and functional device to train switch activation; a second being a low cost device to investigate and implement simple environmental control functions.

A project which clearly demonstrates the process is the development of the commercially available Expanded Vocabulary Augmentation (EVA[2]) Communication Device. This project was developed to address the identified clinical problem of insufficient room on standard wheelchair laptrays to accommodate augmentative communication systems incorporating more than 200 symbols or items. Once the problem was identified and a review of existing technology and literature revealed no current solution, the concept of a tray consisting of rotating prisms activated by a single switch was developed by the team. A prototype was constructed and judged to be promising for further pursuit. A core team submitted a grant proposal and funding was secured from the Easter Seal Research Institute of Ontario to develop the device and evaluate it clinically. Following extended field evaluation, technical problems were resolved, a further version was developed and was eventually handed over for commercial production to the Variety Village Electrolimb Production Centre (now Variety Ability Systems, Inc.).

Additional projects currently being developed by the team include: a modular wheelchair tray with tilt mechanism and fold-away feature (originally funded by the National Health Research and Development Programme and the Hospital for Sick Children Foundation) now in phase four of development for the second time; and the TALK-O[3] a digitized, programmable speech output device incorporating multiple access options presently at stage 5 in co-operation with the National Research Council of Canada - Rehabilitation Technology Unit.

CRITICAL ISSUES

In examining the process outlined above, several critical considerations emerge.

The Team

It is important to have a team drawn from both clinical and technical disciplines. Members should be consistently involved throughout the process and if possible should be encouraged to develop working relationships in several projects. Although each member brings a discrete perspective, mutual understanding and respect of roles is imperative. To fully develop the technical input of the team, opportunities for direct client contact on an ongoing basis is vital. Likewise clinical members must have oppotunities to explore and appreciate the complexities of the technology being investigated.

The Starting Point

It is important to begin with a clear outline of the clinical need. These needs must be well defined, specific and detailed. The process of detailing such requirements is a learning experience for most clinicians.

Communication

Open communication is vital throughout the process. Clinical and technical team members must work closely together and feel comfortable requesting advice and providing feedback and criticism on an ongoing basis.

Development of this open communication is a major challenge to be met in order to ensure efficient team interactions. Problems in terminology and interpretation are particularly apparent in disciplines as diverse as those called upon in such collaborative projects.

Negotiation

The pursuit of the "ideal" solution is often not a realistic approach due to time and financial considerations. Therefore, team members must learn to compromise appropriately and effectively. Requests and decisions must be carefully evaluated for their impact on the specific project. Team members must develop the expertise and knowledge to understand when compromises can be made and would result in an acceptable solution and when compromise would defeat the project.

CONCLUSION

The evolution of the collaborative efforts described has been a challenging and exciting experience. In addition to achieving greater harmony and understanding between team members and departments, numerous projects have been developed which have truly addressed identified clinical needs. Further exciting interactions are envisaged at HMMC. It is hoped that as the field evolves increased clinical involvement in technical development will develop.

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DESIGNING A COMPUTERIZED VISUAL COMMUNICATION SYSTEM FOR SEVERE APHASICS

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ABSTRACT

The Rehabilitation R&D Center of the Palo Alto Veterans Administration Medical Center has been developing and evaluating a Computer-based VIsual Communication system (C-VIC) for severely impaired aphasics. Cognitive and motoric impairments often accompany the linguistic deficits in aphasia, and it is important to consider the aphasic patients' residual capabilities in developing the system, because these capabilities must be utilized in rehabilative efforts. Available technology must be considered as well.

Our C-VIC system has been developed on an Apple Macintosh computer, which is affordable, compact, and features high-resolution graphics. The design features of the C-VIC system, including considerations of the aphasics' abilities and deficits, will be discussed.

INTRODUCTION AND BACKGROUND

Aphasia is the loss of ability to understand or produce normal spoken and written language after damage to the brain, usually following head trauma or stroke. Typically, aphasics are given traditional speech therapy following their brain injury, but approximately half do not recover functional language ability, even after several months of therapy and the effects of spontaneous recovery. They remain severely language-impaired, and frequently have cognitive and motoric impairment as well. Many current commercially available communication devices are not suitable for aphasic patients because the aphasics lack the necessary linguistic skills.

For these individuals, Visual Communication (VIC, *ie.* concatenation of visual symbols into syntactic strings to form sentences) has proven useful. Early work with aphasics using visual communication (1) showed that some severely impaired aphasics were able to achieve a level of communication using VIC that exceeded their natural language ability. This early work was implemented on index cards, whereby iconic symbols were drawn on cards, and aphasics could select individual cards from piles and concatenate them on a table. Although communication improved for aphasics using VIC, there were several limitations with using cards, including difficulty with manipulating large numbers of cards (because of hemiplegia, which is common to aphasics), and lack of ability to translate symbols into English.

Many of the limitations of the card-based system have been addressed by adapting VIC to a computer. In developing the computerized VIC system, the researchers on the project must consider the linguistic and motoric deficits and abilities of the aphasic users. By utilizing the residual capabilities of the aphasics and attempting to provide additional communicative leverage with the computer, the system can be developed to its greatest potential.

DESIGN FEATURES AND CONSIDERATIONS

Below some of the features of the system that have been adapted to the aphasic patients' deficits, their residual abilities, and available technology are described.

Graphic Display

High-resolution icons are arranged on an Apple Macintosh screen into "stacks" of cards which the user can select and concatenate into syntactic strings. This card metaphor was implemented because of its success in the earlier work described above. The card metaphor is also successful with the computer implementation.

The high-resolution of the graphic display allows for easily recognizable iconic images. The ability to recognize pictures remains intact for most aphasics, so visual icons can be learned. Many of the representations of the lexical items are quickly learned by aphasics, particularly representations of objects (common nouns) because of their similarity in appearance to their real-world reference. Additionally, video snapshots can be used to identify people (proper nouns) in the system for easy identification by users. Figure 1 shows a sample C-VIC sentence which includes a video snapshot and an easily recognizable common noun.

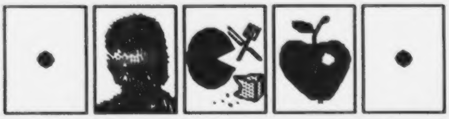

Figure 1. Sample C-VIC sentence. English translation: "Gloria eats the apple."

Flexibility

Flexibility of the system is important to meet the variety of patients' different skills and needs. The C-VIC system allows the vocabulary to be tailored to the user, both in size and in composition. Aspects other than those relating to the vocabulary can be adapted to the patients as well.

Cost

Typically customized equipment is quite expensive to disabled users, whereas commercially available equipment can be available at a reasonable cost. Because only the software for the C-VIC program is customized, the cost can remain low. The Macintosh computer is relatively affordable and is used unmodified. Already two of our aphasic patients have been provided with Macintosh computers and C-VIC software for use in their homes.

Portability

For the C-VIC system to be practical, it must be portable. Users will want to carry it with them for their communications. The Apple Macintosh computer is semi-portable. The two aphasic subjects who have systems in their homes are able to move the computer around to convenient areas in their homes, although they are not yet able to carry it outside of their home, because the computer requires an electrical outlet and is somewhat cumbersome to carry. Lightweight, portable terminal screens and battery packs will make the system more convenient when they become available at a low cost.

One-handed Operation

Aphasics often suffer a right hemiplegia, which led to a difficult time manipulating index cards in the earlier VIC work. Additionally, aphasic patients are often apraxic, causing difficulty with keyboards and writing. With the computerized VIC system, the user can select icons on the screen with one hand using a "mouse". One-handed operation is important to the system because of the lighter motoric demand on the user. A very large vocabulary is impossible using cards, whereas the vocabulary size does not affect the motoric demands when using the computer. One aphasic subject, who was first trained on VIC using cards and then using the computer, decreased his accessing time by as much as 45 seconds per word using the computer with the same size vocabulary.

Hierarchical Organization

Using the computer, icons can be organized hierarchically, which allows a larger vocabulary size. In the C-VIC system, common nouns are arranged in four subcategories: food and utensils, body parts and clothing, appliances and furniture, and sundries and miscellaneous items. Within the main noun category, the user selects the appropriate subcategory, thereby avoiding the need to search through all of the large number of nouns available in the system. Most aphasic subjects have been able to learn the categories with little difficulty, because their real-world contextual knowledge typically remains intact.

Editing and Clean-Up

When users make syntactic errors, editing functions are available to manipulate icons on the screen. An aphasic user can easily insert a space for a missing icon, delete an extra symbol or space, or reverse the order of two icons. This allows the users to manipulate their sentences before completing them. Since some aphasics prefer to select all nouns first and add verbs later, these editing functions have been helpful to make this quite natural.

Also, after a communication has been completed, the computer automatically files icons back to their original pile. Because each card is filed back to its exact location within each pile, users often can and do memorize the location on the screen when they are accessing icons. This was not possible with the earlier card-based system, because cards needed to be manually filed back into their appropriate files and not necessarily in an organized fashion.

Translation

The computer can translate the visual symbols into English words, which permits aphasics to communicate with normal language functioning people who are not familiar with the vocabulary. Clearly, this feature is important to aphasic users who will want to communicate freely with family and friends.

Translation can be helpful at both the word level and at the sentence level. For aphasics with primarily expressive deficits, the English translation of the words helps to more quickly learn the visual symbols and *vice versa*. Normal language-functioning users can find symbols easily using the translation, as they are organized alphabetically. The complete sentence can be translated to natural English and printed below the utterance. Additionally, in the future, a text-to-speech synthesizer could be connected to the system to speak the sentences aloud if desired.

Animation

Verbs are the most difficult items for aphasics to learn because it is difficult for them to recognize static representations of actions [please see Weinrich, et al. and Kleczewska, et al. in these Proceedings for further information on verb learning (2,3)]. We have been adapting the interface to address this difficulty. One problem is that semantically related nouns and verbs can be difficult for them to distinguish. For example, the icons representing *to smoke* and *cigarette* are often confused, even though they are found in different piles. We believe that animating the verbs will help to distinguish such semantically related word pairs, and we are in the process of implementing animation into the system. The representation of *to smoke* will dynamically show the action of smoking, whereas the representation of *cigarette* will be the static image of a cigarette.

Manipulable Windows and Overlays

In addition to the vocabulary items that are organized by their part of speech, the C-VIC system allows special windows to overlay the screen for more efficient space usage. Aphasic patients have been able to operate multiple windows, so it is a valuable tool that can be used for several functions in the system. Two overlay windows are operational in the C-VIC interface to date, although others will be added: a calculator and a clock. The calculator, a standard Macintosh accessory, operates very similarly to a standard pocket calculator, using the mouse or keyboard to access numbers. This calculator has not been difficult for aphasics to learn because of its similarity to the real-world electronic calculator, and it has proven helpful to aphasic C-VIC users in money-counting and other simple mathematical tasks.

The clock, shown below in Figure 2, is animated in its representation. The C-VIC user sets the hour hand and the second hand with the mouse until the clock shows the desired time, and then specifies A.M. or P.M. The clock then reduces to an icon which can be used and translated within any C-VIC utterance.

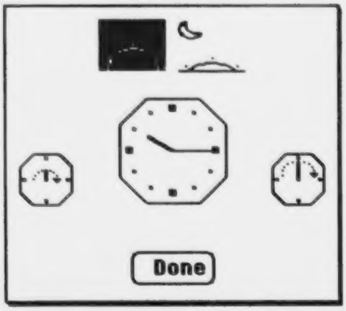

Figure 2. Settable clock which overlays the C-VIC screen.

Artificial Intelligence

Aphasics can recognize contextual cues, and a variety of accessing schemes are being considered to take advantage of this knowledge. In the future, artificial intelligence techniques will be implemented in our system so that contextual information is available to the computer, forcing specialized vocabulary items to be available for selection only in their appropriate contexts. For example, if an aphasic user selects the verb *eat*, only eatable items will be available for selection on the screen, thereby reducing the vocabulary field size for more efficient use. Or, if the user selects the objectival noun *apple* and omits the verb, the C-VIC system will suggest appropriate verbs such as *eat*, *buy*, *wash*, etc., and eliminate inappropriate selections such as *drink*, *talk*, and *walk*.

Additional cueing mechanisms using aphasic patients' ability to recognize contextual context are being considered as well for implementation into future versions of the C-VIC interface. For example, if the aphasic user specifies his environmental context (*ie*. a bank, a restaurant, a hospital ward, etc.), then only appropriate vocabulary items will be available for selection in that context. For example, words such as *deposit* and *bank-teller* will only be available within a banking schema and words such as *waitress* and *menu* will only be available within a restaurant schema.

CONCLUSIONS

Consideration of available technology and specific deficits and residual capabilities exhibited by aphasic patients is important in developing a communication system to suit their needs. Our development of a visual communication system on an Apple Macintosh has successfully met some of the linguistic and motoric needs of five aphasic patients. Although some of the computer capabilities in the C-VIC system are quite abstract and complex, the design of the computer interface has allowed these severely impaired aphasics highly improved communication using the system, despite their severe language and motor deficits. Using the computer, they can ask and answer questions, respond to commands, and describe situations.

Two of our aphasic patients have C-VIC systems in their homes, and we are beginning to evaluate the use of these systems outside clinical setting. As novel needs are encountered outside of the clinic, new developments of the system will be considered to adapt to these needs.

ACKNOWLEDGEMENTS

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VOICE OUTPUT COMMUNICATION AIDS:
A SURVEY AND AN EVALUATION.

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ABSTRACT.

The large number of Voice Output Communication Aids and the increasing interest from clients and therapists call for information on available aids, description of their features and evaluation of their performance.
An international survey on Voice Output Communication Aids, VOCAs, was carried out to be presented in an IPCAS fellowship report. A two-page questionnaire was designed to collect the information from manufacturers which would permit VOCAs to be described in a similar way and compared. The items on the questionnaire are presented.
Evaluation of VOCAs is discussed and the IPCAS evaluation protocol is described. This protocol is being used in the evaluation of Multi-Talk a new portable and multi-lingual VOCA. Multi-Talk was received very positively by the first users who appreciated the quality of speech, the ease of operation and the features that speed-up the communication rate.

INTRODUCTION.

An increasing number of Voice Output Communication Aids (VOCA) are available on the market and they reveal a big variation of size and performance. Professionals who have no or very little experience with speech output aids need explanation of the performance and guidance for selecting appropriate aids for their clients. Surveys and evaluation studies can provide valuable information to professionals who otherwise have to rely on pamphlets and other sales information.

The need for more information in the field was identified by the IPCAS committee which decided to give the IPCAS fellowship to Gunnar Fant to write a report on VOCAs. He invited Sheri Hunnicutt and myself to join him in this task. The report describes the technical solutions for speech output, quotes users' opinion, gives case histories and summarizes the experiences of people involved with these aids. It further presents a summary of the aids available and gives some perspective about the future.

A SURVEY ON VOCAS.

We decided to carry out a survey to collect information on VOCAs from manufacturers and developers. For the survey we developed a two-page questionnaire to present information on each device so as to permit cross comparison of different aids. We asked the manufacturers to return camera ready versions of the questionnaires. We intend to publish all material in the coming report.

Before developing the form we looked for some guidelines. The only published material we found was an information chart on commercially available communication aids by Kraat and Sifver (1983). The aids are primarily groupped together as either portable or non-portable. Further division was based on the selection method. Selection techniqes, language content, types of output, portability and price range are specified.

We wanted our survey to contain a more detailed description, so our questionnaire covered the following items.

1. Name of the device, type and manufacturer/-distributor/developer.
2. Portability, powering (battery or mains) and whether a stand alone aid or not.
3. Method of speech genaration, speech chip or module used and available languages.
4. Other outputs (visual display, printer etc.)
5. Language input: spelling/words/symbols/pictures and vocabulary size.
6. Selection modes, number of levels, whether encoding options are included.
7. user motoric ability required.
8. User programmable features.
9. Size and weight.
10. Accesories.
11. Refences, evaluatiions, case studies.
12. Additional information.

Sufficient space was allocated to the last item to allow insertion of a photograph and any further information, e.g. a fuller elaboration of earlier items where not sufficient space had been provided, or any new information not specifically elicited in the earlier items.

As a result of the survey, information on 39 devices was supplied by 32 manufacturers and developers. All the devices are not truly commercial according to the criterion used by Kraat and Sifver, but in our survey this was not a criterion for exclusion.

The material from the survey could be used to classify the VOCAs. However, it was not the specific purpose of this paper or of the IPCAS report. The material rather was structured so it would be maximally easy for a potential buyer to identify which aids in the survey would fulfill his individual requirements.

EVALUATION OF VOCAs.

The people who need communication aids compose such a heterogenous group that it is not possible to carry out well controlled evaluation experiments. We have to rely on subjective assessment and the judgment of professionals with long experience. Case studies can provide valuable information if published in a way that allows other professionals to understand the conditions and interpret the findings. If we are to carry out evaluations experiments, it would seem sensible to use a uniform experimental design and method for reporting procedures and the findings. However, such a strict formal approach carries the risk that for individual cases some items may not fit well and thus valuable information may be lost. It is therefore important to allow enough flexibility and give space for comments along with the formalized questions.

The above considerations led to development of an evaluation protocol within the International Project on Communication Aids for the Speech-impaired (IPCAS). The protocol is devided into two sections: the first one deals with technical matters. The second, dealing with clinical issues, as follows.

- information on the aid,
- who made the evaluation and where,
- duration of the study and frequency of use
- diagnosis and other data on the user,
- motor and mental ability, hearing, vision
- reading and writing ability
- introduction of the aid and its use,
- whether special adaptation or additional technical aid was required.
- the user's way of operating the device,
- previous experiences of similar aids,
- pre-training and initial difficulties,
- place and kind of communication events,
- usefulness and ease of handling,
- communicative behaviour befor and after,
- extent to which it helps the user attain independence,
- acceptance by the user and the environment
- requirements on the receiver,
- break-downs and technical problems,
- security and durability,
- desired changes or additional features,
- present and estimated future usefulness
- other findings and suggestions.

The IPCAS protocol is available in English from the IPCAS Secreteriat, CRCD, Suite 2110, One Yonge Street, Toronto, Canada M5E 1E5 or from the Swedish Institute for the Handicapped Box 303, S - 161 26 Bromma, Sweden.

EVALUATION OF THE MULTI-TALK.

The IPCAS protocol has been used and found useful in several evaluation studies in Sweden and found valuable. It was considered also for the evaluation of a new VOCA, the Multi-Talk. The latter is a portable, multi-lingual communication aid, basically a text to speech system with high quality synthetic speech. In the form of an attache-case, it contains a sythesizer modul from Infovox and an Epson HX-20 computer.

There are several features built into the device to increase the rate of communication. The design allows for varying the voice as between male, female and child and for changing the voice quality from modal voice to whisper. The device can be used in four languages (from a possible choice of eight). Where for a given language the pronunciation of certain words do not follow the normal rules, this can be specified and stored permanently by the user.

Figure 1. The Multi-Talk.

It transpired that the protocol as it stood, would have a number of questions unanswered,

- judgement on the quality of the speech by the user and the environment,
- preference for a specific voice,
- how the specific features for speeding up the rate of communication were used,
- how the feature for exceptional pronunciations was used, etc.

A couple of the original items were not applicable and were replaced by the new ones. Some of the questions were extended in order to give more detailed information.

It is planned to carry out the evaluation project with five Multi-Talks involving ten speech impaired people with different backgrounds, abilities, education and needs. The main focus was on the use of the device as a communication aid. However, pedagogical applications have been identified and many inquiries received concerning the use of Multi-Talk as an aid for developing reading and writing skills. Several Multi-Talks had been bought by schools for the same approach.

A requirement in selecting subjects for the evaluation was that the user should have the support of one person on site who would take the responsibility for the evaluation. Another criterion related to ethical reasons: it had to be subsequently possible for the aid to be prescribed if the experiment were to show that the user benefitted from it. For that reason in the planning of the project, we tried to involve the aids centers responsible for supplying our subjects with aids.

Seven of the ten subjects have cerebral palsy and three have other reasons for their speech impairment: muscular disease, meningitis and cerebro-vascular hemorrhage. Mentally they are normal or close to normal. Six of them can operate the ordinary keyboard of the Multi-Talk with their hands (two of them need key-guard which is one of the accessories available), the other four can type with a head-stick. Three of them are adults and three are children under 10 years. The remaining four are teenagers. With the exeption of the small children all the subjects can read and write well. The purpose of including the children is to study how much impact the use of the Multi-Talk will have on their reading and writing skills.

So far three individuals in the project have started using the Multi-Talk. They received a detailed introductory training lasting between 2 and 4 hours. They learned quickly to use most of the features on that occasion and started to store individual sentences for quick retrieval. One of them uses the aid frequently for telephone conversation. She prepares most of what she intends to talk about in advance and uses a loudspeaking telephone successfully. She is the only person in this study who has had previous experience in communicating with synthetic speech. She has had the benefit of studying phonetics in the past, and has become adept at programming for words with exeptional pronunciation.

These first experiences are promising: the quality of the speech is good enough for all kinds of communication, including telephone conversation and talking in groups. The users appreciate the choice of voices, the quality of the synthetic speech, the ease of operation, the portability and the features that speed-up the communication rate.

This project is scheduled to run until the end of June. The final report will be completed before the end of September 1987.

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PRELIMINARY VALIDATION OF PRESCRIPTION GUIDE FOR SELECTION OF COMMUNICATION AIDS

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ABSTRACT

The Tufts-MIT Prescription Guide is a computer-managed, predictive assessment and computerized decision procedure for communication device selection. Preliminary validation was carried out by collecting data from 11 experienced device users with severe communication deficits. Correlation between predicted and observed communication rate, and agreement between use and preference predictions and observations was measured.

Predicted and observed rate correlated at .836 ($p<.005$). When amount of use and preference rating favored the same device, they also agreed with Benefit score in 5/5 cases. Including cases in which use and satisfaction rating favored different devices, Benefit score predicted use 7/9 times and satisfaction 6/8 times. These results provide support the predictive validity of the Guide.

INTRODUCTION

The Tufts-MIT Prescription Guide was designed to provide support for clinicians and consumers seeking an augmentative communication device which will maximize the client's communicative function. The Guide, which is implemented on an IBM PC-compatible, works by bringing to bear a body of data which completely specifies a number of communication devices; and a body of knowledge about augmentative communication from judgments made by clinicians and researchers and from results of objective experiments. The device data and the expert knowledge are incorporated in the system as formulas and algorithms and automatically processed with each client's assessment data, to produce scores representing the suitability of each device to the individual client's needs and abilities, and predictions of user-device performance. Client data is acquired using a set of procedures some of which involve computer-prompted keyboard data entry, and some of which use test equipment directly connected to the computer, which prompts task selection, presents some tasks on the monitor screen and acquires data.

Preliminary versions of the system have been described elsewhere (Goodenough-Trepagnier & Rosen, 1982; Rosen et al., 1985), and a brief description of the system as it is currently constituted has been submitted for publication (Goodenough-Trepagnier, et al., submitted).

SUBJECTS

The eleven people who provided the data reported here ranged in age from 15 to 45. Eight were male. Etiologies were traumatic brain injury (4), cerebral palsy (4) and one case each of brain stem stroke, Joseph's disease and anoxic brain injury. All were users of spelling-based communication systems, which included alphabet and alphabet plus word boards, Memowriter, Speechpak, Expanded Memowriter, Canon, Autocom and Express-3.

Rate Prediction Study

One component of the system, which acts on client motor ability data and specifications of device characteristics including geometric properties and language menu and key assignment, produces as its output score a prediction of ceiling communication rate. A test of the system's validity therefore includes a test of correlation between predicted rate ceiling and measured rate of output by people who have become experienced users of their device. Experienced users were studied because the prediction is based on motor data acquried under conditions of minimal cognitive demand, and is designed to be relevant to performance at expertise, after learning has levelled off.

All subjects for this study were users of planar keyboards of some type, including both inert and electronic aids. The motor assessment protocol dealt with sensitivity of movement time to target (key) width, inter-target distance and angle of movement, for all subjects, and key force and travel in addition, for subjects assessed with a later version of the protocol. Each person's movement time dependence on task parameters was then modeled by the Guide software as linear equations expressing the dependence of movement time on the task variables.

Measurement of actual time for production of each sentence was measured by stopwatch timing from the first to the last keystroke or selection gesture used to produce each sentence. Mean observed time per character was calculated by dividing by the number of characters in each sentence. For non-electronic language boards, the receiver's spoken feedback of the last selection was taken as marking the end of the sentence production.

Each sentence to be produced by a subject in the message reproduction task was processed by a program which decomposes text into the sequence of motor acts required to produce it on a given device. The time predicted for each motor act and thus for each character was calculated from the subject's motor model. These times were averaged to derive the mean predicted time per character.

Motor assessment and communication rate measurement were carried out by different members of the research team in all cases. Motor assessment was separated in time from rate measurement by at least 1 month.

Results of Rate Prediction Study

A correlation coefficient, r, was computed for predicted and observed time per character across the 10 subject-device pairs for which rate measurements had been obtained. The value was 0.836, with a probability of chance occurrence of less than 0.005. This high degree of correlation provides support for the relevance of the tasks which make up the motor assessment to the functional activity of producing English messages on clients' communication boards and devices.

In 7 / 10 cases, predicted time per character was shorter than measured time per character, as expected. One of the remaining three subjects occasionally used two fingers to operate her device, resulting in measured rate which is almost as fast as predicted rate. Rate was underestimated for two subjects. In the case of one of these people, a very proficient alphabet board user, this is probably due to the difference between the strict motor demands of the electronic test panel used for assessment, and the less demanding performance required by a receiver of messages produced on a letterboard. Letterboard operation does not require actual contact with the targets, just acceptably clear indication of the intended target to suit the receiver who already has hypotheses, based on language knowledge, about likely and unlikely targets. The underestimate of the remaining subject's performance may reflect lack of control of biomechanical factors influencing movement time during assessment and rate measurement, or inadequate treatment in the processing and modelling of variability in the patient's motor performance. This is under further investigation.

In carrying out the motor assessment, the hand or headstick was being moved, as rapidly as possible, within the limits imposed by trying to maintain accuracy, between pairs of targets, unencumbered by any menu display or message production function. In the message production task, each subject was reproducing prepared sentences. These two tasks were separated by a sizeable time interval. The correlation between predicted rate, based on abstract motor assessment and closed-form modeling, and observed rate in the sentence reproduction task, provides evidence of the validity of the rate prediction component of the Prescription Guide, as applied to performance with planar keyboards.

METHODOLOGY FOR MEASUREMENT OF RELATIVE SATISFACTION AND USE

A four-level verbal scale (Excellent, Good, Fair and Poor) was used to ask subjects to rate their satisfaction with their communication modes. They rated speech or other non-augmentated techniques as well as their device(s). We were thus able to get at how people perceived the incremental benefit of using an augmentative aid over what they were able to do without such support. Subjects were asked to estimate the percentage of their communication served by each of their modes with their main communication partners and with people with whom they interacted less frequently.

Each subject had been interviewed using the Needs Questionnaire developed for the Prescription Guide, which elicited information on needs, activities and living circumstances. These data, along with the rate prediction for each device, are processed by the Guide software to produce a Benefit score for each client-device pair. The score represents a prediction of how well each device will serve the client. Benefit scores were computed for each subject with the device(s) s/he was currently using. The hypothesis of this study was that for each user of two or more devices, the Benefit score would predict which of any pair of devices was preferred and was used more than the other.

RESULTS OF SATISFACTION AND USE PREDICTION STUDY

Agreements between the summary output score of the Prescription Guide (the Benefit score) and each participant's report of satisfaction and use were tallied. This is in effect a sign test. When the Benefit score for device A is greater than the score for device B and satisfaction is reported higher for device A than device B, an agreement is scored between the recommendation of the Guide and user satisfaction.

VALIDATION OF PRESCRIPTION GUIDE

Seven subjects used two devices concurrently at the time of this study, and one used three devices. The three-device-using participant had one pair of devices available to him at his residential school, and one of those devices plus the third available at home. There were thus 9 cases of satisfaction and use comparisons to compare to the Benefit score predictions.

Benefit score was found to agree with the device reported as being used more in 7 / 9 cases. Benefit predicted preference (greater satisfaction) in 6 / 8 cases (one pair of devices tied for satisfaction). In all 5 cases where there was agreement between use and satisfaction, i.e., whenever the subject was actually making more use of the device which s/he also rated as better, both use and satisfaction agreed with the Benefit score.

Reliability of the use reports and of the preference ratings was checked by retest, and by consulting with clinicians familiar with the subjects. Subjects' preference ratings and percentage of time estimates did not always remain constant. However, rank order of devices for both satisfaction and use remained stable across test and retest, in the absence of changes in the subject's physical abilities. One patient with head injury regained some ability to produce speech during this period. While he still rated his speech output device more highly than his letterboard, he no longer wished to use an artificial voice.

In the normal course of events, we might expect that a device rated more highly would be used more than the device rated lower. However this turned out not always to be the case. It appears that while the rating is the user's own expression of preference, actual use depends not only on the client but on the people on whom the client depends. The more dependent the client, because of youth, student status, or physical disability, the more influence others may have on what device is used most.

It is interesting to note that electronic devices were not necessarily preferred over language boards. Neither the Prescription Guide, in its user-device goodness-of-fit scores, nor the participants in the study, exhibited an across-the-board preference for certain features in particular nor for electronic versus inert devices in general.

CONCLUSIONS

Development is in progress to improve the clinician operability of the system, to add components to the motor assessment (a mouse/ head-mouse assessment is being tested), to increase the applicability of the system to patients with cognitive involvement, and to add to the device data base. The preliminary validation results summarized here indicate that the Prescription Guide collects appropriate, relevant client data and operates on it using a valid knowledge base. Additional data gained through testing with new patients in Boston and at several clinical research centers in the U.S., Canada and Europe should provide a more definitive test of the validity of the system and its components, and a base for further development to enhance its usefulness to clinicians and device-users.

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SPEECH RECOGNITION OF IMPAIRED SPEECH

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ABSTRACT

SRI is studying the feasibility of a voice driven communication system for impaired speakers using automatic speech recognition. We are testing a template-based isolated-word speech recognizer to see if it can be used to recognize words spoken by impaired speakers whose speech is unintelligibile, but reasonably distinct and consistent. Such a system might decode unintelligible impaired speech and then recode it as more intelligible synthetic speech or as a printed display.

Our studies show that a speech recognizer can sometimes outperform human listeners for isolated words. People often have a difficult time understanding distorted words of impaired speakers, but the recognizer uses the acoustic pattern, where only consistency and distinctness are important. With meaningful sentences, however, the advantage of linguistic context often enables listeners to outperform a speech recognizer.

INTRODUCTION

SRI has been studying the feasibility of a voice input communication aid based on isolated-word speech recognition. We are testing to see if a high-performance template-based speech recognizer can be used to recognize words spoken by impaired speakers whose speech is not well understood by human listeners. For such a communication aid to be successful, the input messages do not necessarily need to be spoken correctly from the point of view of a human listener, but they must be spoken consistently and distinctly. If each word is said the same way each time it is spoken, and each word is distinct from every other word in the vocabulary, then a speech recognizer can match an input message to stored word templates, regardless of whether the message resembles normal English pronunciation.

BACKGROUND:

At the 1985 RESNA conference, SRI presented results of a pilot study comparing the accuracy of a speech recognizer to that of human listeners when recognizing 40 words spoken by five speech-impaired deaf talkers [1]. All five speakers were better recognized by the device than by human listeners, three of the five by more than 60%. The current work reported here is aimed at extending the results of the pilot study to a larger vocabulary (300 words) and a larger subject population (80-100 speech-impaired individuals), and at identifying types of speech disabilities for which such a device would be useful.

Other investigators have also begun testing speech recognition interfaces to communication aids or computerized environmental control systems with speech-impaired users [2-7]. A head-mounted microphone leaves the hands and eyes free and reduces the potential for the mechanical failures that are common with keyboards or electromechanical switches. Voice input can also increase message entry rate compared to mechanical interfaces such as switches, joysticks, etc. Several speech impaired subjects have successfully used a speech recognition interface with a small vocabulary. Among the studies of speech recognition of impaired speech, SRI's work [1,8] represents both the largest subject population and the largest vocabulary.

METHODS AND MATERIALS

Recording

Approximately 50 speech-impaired subjects of several etiologies (primarily hearing-impaired and cerebral palsied) have been recorded and another 30 will be recorded during this two-year project. Each subject is recorded twice, in sessions spaced at least one week apart. During the first session, each subject reads a list of 300 words (see [8]) in a randomized order, three times through. The 300-word vocabulary was selected to include a subset of *common* English words, a set of linguistically *diagnostic* words, and a subset of acoustically *distinct* words. During the second session, the speaker again reads three repetitions of the same 300 words, and then reads once a 65-word story paragraph comprised only of words found in the 300-word vocabulary). Speakers are instructed to pause briefly between each word in the story. The subjects also paraphrase the story, pausing briefly between each word as they speak, so we can determine speech rates in this mode of spontaneous word-at-a-time speech.

Speech Recognition

The recordings from the first session are input to the speech recognizer to make training templates. The three recordings from the second session are also input to the speech recognizer. They are compared to the training templates, and the closest matches are used to calculate the percentage of correctly recognized words.

In addition to testing speech recognition on the entire 300-word vocabulary and the 65-word story, smaller vocabulary subsets are tested separately to measure the effect of different sizes and types of vocabularies on recognition accuracy. When a recognizer operates with fewer words, recognition accuracy generally improves because the number of potential confusions is reduced. Subsets tested separately include:

1) 50 phonetically balanced words from the A.I.D.S. test (Assessment of Intelligibility of Dysarthric Speech [9])

2) 28 words including the 26-word I.C.A.O. (International Civil Aviation Organization) distinct alphabet plus the words *Spell-Mode* and *Word-Mode*,

3) 20 words previously used to test speech recognition of cerebral palsy speakers [7],

4) 17 common multi-syllable words, and

5) The 65-word story paragraph, which contained 50 different words selected from the 300-word vocabulary. Because it seemed likely that the speakers would read words spoken in context somewhat differently from words spoken in citation form (list reading, as in the training), we tested the story words in both speaking modes: in context (65 words read once) and in citation form (50 words spoken three times). Unlike the tests with the other vocabulary subsets, the entire 300-word vocabulary was operational when the story words were tested.

These vocabulary subsets and references to their sources appear in Carlson, Bernstein and Bell [8].

Intelligibility

In order to test intelligibility reliably, we wanted six listeners to hear each speaker. Each listener heard a combination of six vocally impaired subjects speaking a total of 48 isolated words and the 65-word paragraph. The order of speakers was rotated for each listener, and samples of each speaker were heard by six different listeners. Because the study is so large, however, it would be impractical to have six listeners for each of 80 speakers, so instead, each listener hears short samples of a combination of six speakers. Even though it would be desirable for longer samples of speech to be heard, this method produces a relative estimate of intelligibility sufficient for our present purposes.

The percentage of words that were correctly understood by the listeners was calculated for each speaker. Intelligibility was calculated separately for isolated words and for words that were heard in a story context.

RESULTS

Table 1 shows the results of the recognition testing for the first 46 subjects with the various subsets. The recognition accuracy generally depends on vocabulary size; accuracy decreases with larger vocabularies. For vocabularies with 20-50 words, however, high recognition rates by the speech recognizer can be found for most impaired speakers.

Table 2 shows a comparison of recognition accuracy by the speech recognizer and the intelligibility to human listeners for the 46 speakers. Table 3 shows t-test values comparing the recognition and intelligibility data from Table 2 for the hearing-impaired and the cerebral palsied populations. Paired t-tests were done to compare recognition and intelligibility within each population, and unpaired t-tests were done for comparisons across the two subject populations.

For both the hearing-impaired population and the cerebral palsied population, the speech recognizer generally outperforms listeners for isolated words ($p<.01$). The machine recognized the isolated words better for 35 of the 46 speakers studied to date.

When words are read in meaningful sentences, however, listeners generally outperform the speech recognizer. ($p<.01$ for cerebral palsy and $p<.1$ for hearing-impaired). The machine recognized words spoken in context better than the listeners for only 12 of the 46 speakers.

Generally, the speech recognizer was more successful for the hearing-impaired subjects than for the cerebral palsied subjects, for both isolated words ($p<.01$) and contextual words ($p<.05$). With listeners, neither isolated words nor contextual words showed a significant difference between the two populations.

As might be expected, the speech recognizer performed better for words read in citation form than for words read in context ($p<.01$), because the words were originally trained in citation form. Generalizing the training of the recognizer to include speech in story form may improve recognition.

DISCUSSION

For isolated words from impaired speakers, our studies show that the automatic speech recognizer can often outperform human listeners. Listeners have difficulty understanding the distorted words of impaired speakers, whereas the recognizer relies on the acoustic pattern, where only consistency and distinctness are important. When speakers talk in meaningful sentences, listeners gain the advantage of linguistic context; the machine does not yet have this capability. It remains to be seen how contextual information can be programmed to the speech recognizer to improve its performance. If training of the recognizer can take into account the variation of words spoken in context (perhaps by storing multiple templates), words spoken in context may be recognized as well as words spoken in isolation.

Our revised method for comparing listener performance to recognition device performance indicates that a smaller percentage of impaired speakers are likely to benefit from speech recognition for augmenting their communication than the pilot study suggested using our original method [1]. However, there remain some 20-30% of the speech impaired subjects we have studied that are better understood by machine than by listeners. For these people, it seems that if they can reliably produce more information by voice than by other motoric modalities (*e.g.* manual actuation), there is a potential for speech recognition to help in their communication. For example, hearing-impaired speakers who are recognizable by machine may benefit from speech recognition in the deaf-hearing telecommunication system SRI has been developing under NSF support [10].

For those speech impaired people for whom speech recognition is not advantageous in applications requiring large vocabularies and contextual speaking, other applications may be valuable. Speech recognition may be a more generally appropriate tool for certain applications requiring small vocabularies, such as environmental control.

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TABLE 1
PERCENT CORRECT MACHINE RECOGNITION FOR SUBSET VOCABULARIES

Subject	Etiology (see key)	Age	entire vocabulary and story (300 words)	A.I.D.S. vocabulary (50 words)	I.C.A.O alphabet (28 words)	Rodman vocabulary (20 words)	multi-syllable words (17 words)
1	HI	18	71	90	93	97	100
2	HI	16	78	94	95	97	100
3	HI	16	84	90	93	100	98
4	HI	16	84	90	100	100	96
5	HI	16	80	89	99	98	94
6	HI	16	70	89	92	97	96
7	HI	37	40	59	58	82	69
8	HI	23	77	93	93	100	100
9	HI	21	62	83	98	95	90
10	HI	25	69	85	95	95	94
11	HI	29	67	80	88	88	98
12	HI	34	44	57	64	72	88
13	HI	34	58	82	90	93	98
14	HI	21	6	22	31	38	31
15	HI	21	49	75	89	82	100
16	HI	23	81	93	99	100	100
17	HI	23	81	92	98	98	100
18	HI	19	41	72	87	73	88
19	HI	20	40	67	82	92	96
20	HI	22	56	81	87	93	82
21	HI	18	71	87	94	97	100
22	HI	23	22	29	45	57	82
23	HI	21	41	60	79	88	78
24	HI	21	84	94	100	98	100
25	HI	22	42	55	76	90	75
26	HI	27	67	61	75	92	82
27	HI	23	38	58	65	79	74
28	CP	28	57	78	92	82	86
29	CP	36	66	77	89	98	96
30	CP	26	38	68	77	88	88
31	CP	35	64	93	98	90	100
32	CP	33	9	22	35	48	47
33	CP	21	42	71	90	82	80
34	CP	24	9	19	43	48	41
35	CP	43	26	45	61	48	55
36	CP	36	51	63	85	87	86
37	CP	14	14	32	40	43	47
38	CP	26	74	91	98	95	98
39	CP	29	57	76	89	87	73
40	CP	18	50	75	85	80	78
41	CP	12	15	29	49	40	43
42	CP	16	14	30	33	52	55
43	DY	38	52	75	87	90	78
44	HI & CP	27	44	67	79	88	94
45	HT	16	84	93	94	98	92
46	CA	17	46	72	90	77	90

TABLE 2
COMPARISON OF MACHINE AND LISTENER RECOGNITION FOR IMPAIRED SPEAKERS

Subject	Etiology (see key)	Age	Percent Correct Machine Recognition		Percent Correct Listener Recognition	
			story words spoken in "citation form"	story words read in a narrative	selected isolated words	story words read in a narrative
1	HI	18	67	65	27	74
2	HI	16	75	78	92	95
3	HI	16	87	74	71	92
4	HI	16	85	78	83	100
5	HI	16	75	82	81	100
6	HI	16	64	77	79	100
7	HI	37	46	40	6	20
8	HI	23	75	55	67	92
9	HI	21	62	49	60	92
10	HI	25	77	55	21	22
11	HI	29	69	52	40	57
12	HI	34	39	35	29	42
13	HI	34	64	48	27	68
14	HI	21	7	3	2	5
15	HI	21	49	31	38	85
16	HI	23	73	58	79	98
17	HI	23	77	72	60	98
18	HI	19	40	17	4	9
19	HI	20	38	20	8	3
20	HI	22	55	45	13	25
21	HI	18	66	69	46	89
22	HI	23	21	14	10	11
23	HI	21	43	26	8	12
24	HI	21	79	69	92	95
25	HI	22	51	45	25	45
26	HI	27	50	31	10	15
27	HI	23	44	35	8	8
28	CP	28	55	43	56	94
29	CP	36	68	49	27	48
30	CP	26	34	26	40	85
31	CP	35	63	55	48	88
32	CP	33	11	6	6	11
33	CP	21	43	32	46	74
34	CP	24	7	5	2	0
35	CP	43	23	22	19	29
36	CP	36	61	46	33	69
37	CP	14	16	9	6	17
38	CP	26	79	69	56	100
39	CP	29	57	37	27	71
40	CP	18	46	51	46	98
41	CP	12	15	11	15	37
42	CP	16	16	5	8	25
43	DY	38	48	22	10	9
44	HI & CP	27	43	38	42	80
45	HT	16	86	82	85	98
46	CA	17	43	35	58	85

Etiologies

HI: hearing-impaired
CP: cerebral palsy
DY: dystonia
HT: head trauma
CA: cancer (lymphoma) with neurological complications

TABLE 3 -- T-TESTS OF DATA REPRESENTED IN TABLE 2

	CP: listeners isolated	CP: listeners context	CP: machine isolated	CP: machine context.	HI: listeners isolated	HI: listeners context	HI: machine isolated
HI: Machine-context				t=2.6 p=.014		t=-1.9 p=.064	t=-5.4 p=.000
HI: Machine-isolated			t=2.8 p=.008		t=4.7 p=.000		
HI: Listeners-context		t=0.1 p=.928			t=5.8 p=.000		
HI: Listeners-isolated	t=1.3 p=.211						
CP: Machine-context		t=-5.0 p=.000	t=-4.9 p=.000				
CP: Machine-isolated	t=3.0 p=.011						
CP: Listeners-context	t=6.3 p=.000						

A COMPARISON OF PALANTYPE AND STENOGRAPH KEYBOARDS IN HIGH-SPEED SPEECH OUTPUT SYSTEMS

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ABSTRACT

Palantype and Stenograph are shorthand stenotype keyboards upon which words can be typed, in coded phonetic form, at natural speech rates. They can be used as control interfaces for phonetic speech synthesisers, realising systems which have potential applications as communication and rehabilitation systems for the sight impaired, speech impaired and hearing impaired. The Palantype and Stenograph keyboards are compared, in theory and in practice, as control devices for stenotype-to-speech systems.

PALANTYPE, STENOGRAPH AND SPEECH SYNTHESIS

Stenotype keyboards are high-speed typing keyboards which can be operated, by skilled stenotypists, at natural speech rates (120-200 words/minute). They are used conventionally to produce verbatim records, in coded form, of spoken information, and are employed extensively in the transcription of proceedings in Courts of Law. The Palantype is a British stenotype keyboard, and the Stenograph is an American counterpart (Figure 1). Both use syllabic and phonetic coding methods to facilitate typing at natural speech rates. Each keyboard has a central group of vowel keys, a left-hand group of initial consonants, and a right-hand group of final consonants. A trained stenotypist would record spoken proceedings by **a)** segmenting each spoken word into its constituent syllables, **b)** spelling each syllable phonetically, **c)** encoding this phonetic spelling for the keys available on the keyboard, and **d)** typing the syllable in a single multi-key stroke (or "chord") on the keyboard. Some phonemes, not represented explicitly on the keyboard, are stenotyped as multi-key codes. The Palantype has no B, D or G, for example, so the codes **P+**, **T+** and **C+** are used in their place.

Electronic transcription systems have been used, in Britain and America, to perform automatic translation of stenotype code into English orthography. Simultaneous transcription of speech, for the hearing impaired and for general commercial purposes, is performed using such methods (1,2,8). Phonetic stenotype keyboards can also be used, however, to control phonetic speech synthesisers. Previous work (3,4,5,6) has indicated that Palantype and Stenograph keyboards can be used as direct control interfaces for phonetic synthesisers, the unrestricted vocabulary and high speed of operation making possible a fast and expressive communication medium.

CONVENTIONAL AND PHONETIC STENOTYPE PRACTICE

In principle, stenotypists should encode words exactly as described above, using rigorous phonetic coding. In practice, however, they can use abbreviations, and ambiguous and non-standard codes, in order to improve their stenotyping efficiency and reduce fatigue. Palantypists have been found to adhere much more strictly to a standard and phonetic coding method than their Stenograph counterparts (8). Because of such non-phonetic and non-syllabic coding, Steele et al. (3) have proposed that a rigorous phonetic ("phonemic syllabic" or "PS") coding method should be used by operators of a Stenograph-controlled synthetic speech system, in contrast to the conventional method ("traditional courtroom" or "TC") found in commercial practice. Steele lists several examples of character clusters which cannot be stenotyped in a single syllable-chord on a Stenograph keyboard, and suggests that new codes should be developed to represent such missing clusters (4).

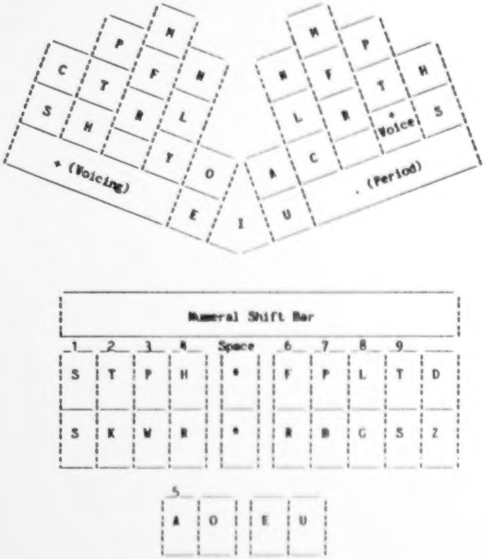

Figure 1: Key Layouts of the Palantype (top) and Stenograph (bottom) Keyboards.

Another, simpler, approach is to ensure that every phoneme can be represented by at least one stenotype code. It is then possible to stenotype any sequence of phonemes, segmenting words non-syllabically where necessary. This method can be termed "full phonemic", or "FP", stenotyping to distinguish it from "phonemic syllabic". It is necessary to ensure that each phoneme is represented by at least one stenotype code, and to devise new stenotype codes to achieve this.

While it is not essential to have every consonant phoneme represented on both sides of the keyboard, it is preferable to do so in order to facilitate syllabic word segmentation. Palantype is well equipped in this respect, because it has more keys (29 keys) and is more symmetrical in layout, but the Stenograph (23 keys) is less well appointed. It has no /SH/, /TH/ or /V/ codes in consonant-final positions, for example, and no /Z/ code in the consonant-initial position.

Certain phonemes (9,10) are not represented at all on either keyboard. There are no unambiguous codes for the voiced /THV/ (as in "this" and "scythe") or the voiced /ZH/ (as in "rouge" and "measure"). There are also some relatively insignificant instances of ambiguous diphthong codes. Suitable new codes are developed easily for Palantype; the voicing key on each side of the keyboard can be used to distinguish /TH/ and /SH/ (unvoiced) from /THV/ and /ZH/ (voiced). Stenograph has no voicing key, however, so it is less easy to develop appropriate new codes. The error key (*) could possibly be used as a "voicing" key if it were moved closer to the consonant keys, or the numeral shift bar could be re-defined as a "voicing" key, but neither of these are ideal solutions. The Palantype keyboard is therefore better equipped for encoding a full range of English phonemes.

ESTIMATED WORKLOAD IN STENOTYPING

Some measure of the relative physical workload incurred by operation of these keyboards can be obtained by calculating the numbers of key-strokes, finger-strokes and chord-strokes required to encode a given corpus of words. Such a measure takes no account of finer ergonomic detail such as distance of finger movement or depth of key travel, but a useful comparison can be achieved nonetheless. Steele (7) has used this approach to estimate the relative physical workload incurred in stenotyping, in TC method on a Stenograph (S), the 100 most common English words, and the author has made similar estimates for Palantype (P). There are 111 (P) and 102 (S) chord-strokes, 321 (P) and 275 (S) finger-strokes, and 363 (P) and 341 (S) key-strokes incurred in stenotyping the 100 words. The Palantypist uses 8.82% more chord-strokes, 16.73% more finger-strokes and 6.45% more key-strokes than a Stenograph operator. A palantypist working in TC mode experiences a greater physical workload than does a Stenograph operator, principally because Stenograph operators make greater use of abbreviation and other non-phonetic coding practices.

Steele also compared workload indices for TC and PS stenotyping by comparing the TC and PS Stenograph records of a 400-word newspaper article. PS coding required 29% more chord-strokes, 49% more key-strokes, and 15% more key-strokes/chord than did TC coding. One would expect from this that PS coding would reduce stenotyping speed, and hence word rate, on a Stenograph by 30% or more. The present author extended this comparison by recording TC versions of a 200-word text from experienced Stenograph and Palantype stenotypists, and comparing these with his own FP versions. In Stenograph, FP coding required 28.6% more chord-strokes, 56.0% more key-strokes and 21.3% more key-strokes/chord than TC, signifying a similar increase in workload of at least 30%. In Palantype, FP coding required 8.8% more chord-strokes, 14.5% more key-strokes and 5.2% more key-strokes/chord than TC; FP coding should only increase the workload here by approximately 10%. The increase in each Stenograph index was more than 3 times greater than the increase in the equivalent Palantype index. This was expected, because conventional (TC) palantyping is much more rigorous and phonetically accurate than Stenograph TC practice. Further to this, the Stenograph TC version of the text contained 13.3% fewer chord-strokes and 7.2% fewer key-strokes than the equivalent Palantype version. In FP coding, this difference was reversed, the Stenograph version containing 2.5% more chord-strokes and 26.4% more key-strokes than the Palantype FP version. It was concluded that a Palantypist should perform better in FP mode than a Stenograph user.

No estimate was made of cognitive workload, but given that the same basic stenotyping technique is used in both systems, it is unlikely that they differ radically in this respect.

PRACTICAL ASSESSMENT OF STENOTYPE-TO-SPEECH

Monologue Mode

Professional stenotypists were commissioned to operate the stenotype-to-speech systems in monologue experiments, in which prepared texts were typed on the Palantype and Stenograph keyboards. The data from each keyboard were processed in real time by a microcomputer-based rule system and used to control a speech synthesiser. The stenotypists (one trainee and two experienced palantypists, and one experienced Stenograph user) were instructed to maintain a brisk typing rate consistent with low error rate, and to use FP coding. The palantypists achieved mean word rates of 27 (trainee), 47 and 73 (both experienced) words/minute within an initial period of 1-2 hours, with a peak rate of 98 words/minute. The Stenograph operator achieved mean and peak word rates of 89 and 94 words/minute respectively, in TC coding, but when FP coding was attempted the mean rate fell to 52 words/minute. The phonetic quality of the texts typed in TC coding on the Stenograph was poor, because of the shortform codes used for many of the words. The Stenograph operator did assimilate FP coding eventually, however, and produced, at the expense of low word rate, synthetic speech of similar quality to that of the palantypists.

Over a further 1-2 hours of FP stenotyping, the palantypists attained mean word rates of 32 (trainee), 89 and 96 (experienced palantypists) words/minute, with a peak rate of 116 words/minute. The Stenograph user achieved mean and peak rates of 51 and 56 words/minute, although the word rate doubled when this stenotypist was asked to revert to TC coding. FP coding evidently impaired the stenotyping speed of the Stenograph operator to a significant degree, and to a much greater extent than it affected the palantypists.

Practical Stenotype Keying Workload

In order to confirm practically the increase in keying workload, the keying activity incurred by the stenotypists in stenotyping an experimental text was assessed. TC versions of this text (597 words long) were recorded, by experienced stenotypists, on Palantype (P) and Stenograph (S), and compared with the FP versions produced in the stenotype-to-speech experiments. The TC versions contained 4.67 (P) and 4.45 (S) key-strokes/word, and 1.58 (P) and 1.30 (S) chord-strokes/word. The palantypists therefore endured greater workloads on both indices (by 5% and 22% respectively). The FP versions contained 5.02 (P) and 6.28 (S) key-strokes/word, and 1.63 (P) and 1.65 (S) chord-strokes/word. The palantypist was advantaged on both FP coding indices (by 20% and 1% respectively). While none of the stenotypists achieved ideal FP technique in the experiment, the original theoretical deduction was correct; Stenograph is more efficient in TC coding, but Palantype is more efficient in FP coding.

Dialogue Mode

After the monologue experiments, the stenotype-to-speech systems were used in dialogue mode, in which each stenotypist "spoke" to a dialogue partner via the stenotype keyboard. The stenotypist had to rely entirely on the stenotype as the medium of verbal expression, while the partner spoke with natural voice. These unscripted conversations proved to be spontaneous and vital, and indicated that successful communication could be achieved via this medium. The mean speech rates in the dialogues involving the experienced palantypists were in the region of 120-125 words/minute, i.e. within the lower range of natural speech rates. The listener (natural speaker) made, on average, two errors of comprehension in 20 minutes of dialogue. The Stenograph conversation was slower, at 60 words/minute, but there was only one instance of mis-comprehension in an exchange lasting for more than 30 minutes. It was evident that the Stenograph was an effective dialogue medium, but it was somewhat slow when used by a stenotypist unfamiliar with FP coding.

POTENTIAL APPLICATIONS OF STENOTYPE-TO-SPEECH

Stenotype-to-speech systems have potential as high-speed, unrestricted vocabulary speech prostheses for the speech impaired. It is necessary for the user to possess good manual dexterity and linguistic ability, hence laryngectomees may comprise a potential client group. The sight-impaired may achieve vocational rehabilitation as stenotypists, using speech output from their stenotype to facilitate training and skill development. Able-bodied stenotypists, some of whom perform real-time speech transcription for the hearing impaired with their electronic stenotype equipment, might benefit similarly by using speech output during training.

CONCLUSIONS ON STENOGRAPH AND PALANTYPE

Stenograph and Palantype keyboards are effective as control interfaces for speech synthesisers. The Stenograph is less efficient in coding terms when used in full phonemic (FP) mode instead of traditional courtroom method, and FP coding is more alien to Stenograph operators than to Palantypists, but with appropriate training a Stenograph operator could control a speech synthesiser, in real time, at low natural speech rates. Some modest Stenograph keyboard modification may be required to incorporate codes for certain voiced consonants. A Palantypist might be expected to achieve average natural speech rates on a Palantype-to-speech system after appropriate training in FP coding. Both stenotype keyboards can therefore be used as control interfaces for speech synthesisers, and both should be developed further in this application.

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DEVELOPMENT OF A REAL-TIME EXPERT SYSTEM FOR AUTOMATIC ADAPTATION OF SCANNING RATES

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ABSTRACT

Researchers at Louisiana Tech University noted that clients using row-column scanning aids often utilized inappropriate scanning rates. The investigators determined that the technique of expert system development from the field of Artificial Intelligence could be useful for developing an adaptive scanning algorithm. Such an algorithm would be designed to mimic the way that speech pathologists adapt the scanning rates when working with clients. To this end, three pathologists were videotaped while they adjusted the scanning rates of row-column scanning aids for their disabled clients. Information from the videotapes was used to develope the expert system, which was then implemented along with scanning software on a Commodore 64 microcomputer. The expert system was found to achieve an 83.2% accuracy rate.

BACKGROUND

Investigators at Louisiana Tech University noted during testing of a microcomputer-based communication aid / independent living system called ADAPTER (1)(2)(3) that some clients used inappropriate scanning rates. It was felt that even though SLOWER and FASTER commands can be provided, clients may not choose the most appropriate scanning rate. An optimum scanning rate is critical for the success of any scanning aid: too fast, and the user makes excessive selection errors and becomes frustrated; too slow, and the user is again frustrated because he is needlessly making selections at rates less than his potential maximum. The potential also exists that, if the user selects the FASTER command to speed his selection rate while he is especially alert, he may have difficulty later in choosing the SLOWER command if he should become fatigued.

The researchers believed that some means must exist for automatically adapting the scanning rate to suit the individual's abilities. The following criteria were set for the algorithm:

(1) The algorithm must work in real-time. The algorithm should ideally perform decision-making without noticeable hesitation in the performance of the scan (scanning, reading switch, etc.)

(2) The algorithm should constantly monitor performance and alter the scanning rate whenever the user's performance changes. The algorithm should be able to adjust the scanning rate as the user becomes proficient but should be able to detect decreases in performance due to factors such as fatigue or medication.

(3) The success of the algorithm should be objectively measurable.

METHODS

The investigators chose to use the technique of expert system development, part of the Artificial Intelligence discipline, to develop the expert system. Expert system development was chosen for research for two reasons:

(1) the technique provides a systematic means of program development using the experience of experts as a guide, and

(2) the use of experts for this system would provide a means of objectively measuring the success of the system.

Identification

During this phase, a knowledge engineer characterizes important aspects of the problem, such as the participants in the development of the expert system, the problem characteristics, and resources to be used (4).

The three speech pathologists at the Louisiana Special Education Center in Alexandria, Louisiana, were chosen to serve as the expert consultants because they have years of experience in working with a large population of disabled individuals who need and use row-column scanning aids daily. A software and hardware interface previously developed for the Commodore 64 was selected for a test framework for the expert system.

Conceptualization

During this phase, the knowledge engineer seeks to determine the key concepts and relationships in the problem. The knowledge engineer interacts with the expert to try to understand the types of data that are available and the processes involved in the problem solution (4).

Information such as the length of time to delay between selections and the resumption of the scan was obtained through interviews with the experts. However, the experts were unable to verbalize the techniques they use in adapting the scanning rate, so that an alternate method of obtaining the information was necessary.

Videotapes were made of each of the experts working with two clients. The clients' expertise with using row-column scanning aids ranged from poor to very proficient. An onscreen clock recorded time to the nearest 1/10 of a second. The data obtained from these tapes included the scanning rate, the reaction times of the client to the scan, and whether or not for each reaction time the client selected the item that he wanted.

Formalization
During this stage, the knowledge engineer attempts to map the key concepts and relationships within the problem to a more formal structure suitable for a computer program. The model thus prepared may be behavioral and/or mathematical (4).

The expert system was constructed with a mathematical and behavioral model. The mathematical model, based on the mean and standard deviation of each client's reaction times, is used to grossly predict scanning rates. The behavioral model handles special situations such as deciding to decrease scanning rates if the client makes excessive errors and preventing sudden scanning rate changes between row and column selections.

The system parameters were adjusted to achieve optimal performance by using the downhill Simplex minimization technique to minimize the average absolute percent difference between the scanning rates set by the pathologists, taken from the videotapes, and those which would be selected by the expert system given the same reaction times and error rates. The use of the Simplex technique permitted quick systematic evaluation of varying sets of parameters, including the coefficients for mean and standard deviation in the mathematical model, the number of moving samples to use in the statistical calculations, and the impact of varying rules in the behavioral model.

Implementation
During the implementation phase, the prototype expert system is implemented on a computer. Generally a commercially obtainable expert system shell is used to implement the formal structure of the problem solution obtained during the formalization stage (4).

A typical small expert system is expected to take up to one-half hour to find a solution (5). In order to be completely transparent to the user, this particular expert system has to solve the problem of adapting the scanning rate in no more than 500 milliseconds, the delay recommended by the pathologists between item selection and the continuation of scanning. For this reason, as well as for the fact that the problem of adapting a scanning rate is very small compared with problems typically addressed by expert system shells, the system was implemented within the Commodore 64 scanning software already developed.

Testing
This phase involves evaluating the prototype system and the representational forms used to implement it. The prototype is tested with a variety of examples designed to determine its weaknesses (4).

The Commodore 64 row-column scanning aid with the incorporated expert system for adapting the scanning rate was initially tested on the same clients who had been videotaped. The speech pathologists observed the clients while they used the system. Each client's data was automatically recorded on a floppy disk for later analysis. A selection was counted as an error if the client selected the backspace function, if the client selected a row without selecting a column, or if the client selected a column but immediately re-activated the switch to cancel the selection.

Some adjustments were made in the expert system before a second set of trials. To obtain a quantitative comparison between the scanning rates set by the speech pathologists and those set by the expert system, another set of tests was conducted on four clients, two of which had been videotaped and two more of which had not. During these tests, the pathologists were allowed to set the scanning rates with a 10-position switch. The expert system selected scanning rates as it had before, but this time those rates were only recorded rather than used to actually set the scanning rate.

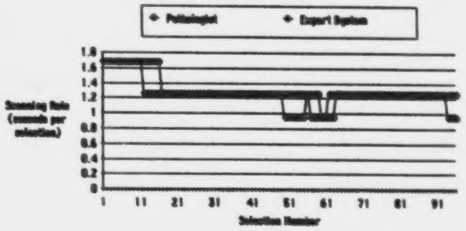
RESULTS

During the first test of the expert system, five out of six clients felt that the system selected "good" scanning rates while one client felt that the rates were "slightly fast". The speech pathologists felt that the scanning rates selected were "good" for four of the clients, but "slightly fast" for the other two.

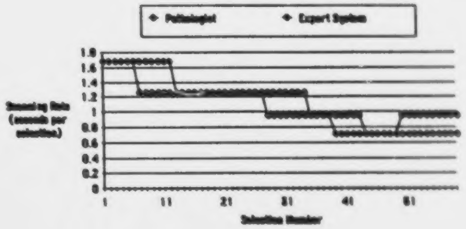
Figure 1 shows the comparison of the scanning rates set by the pathologists to those selected by the updated expert system from the second set of trials. Overall, the expert system was found to achieve an accuracy of 83.2%. The expert system selected exactly the same scanning rate as the pathologists for 59.9% of all client selections, and was off by only one scan rate setting for 31.1% of the selections. The expert system averaged an overall selection rate of 1.27 seconds per selection to the pathologists' 1.20 seconds per selection.

Figure 1. Comparison of the performance of the expert system to the performance of the speech pathologists.

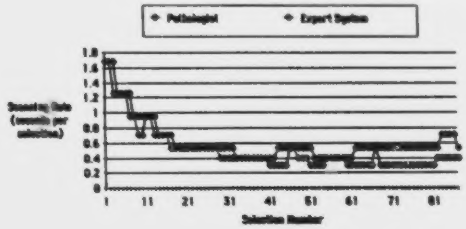
(a) Videotaped client #1



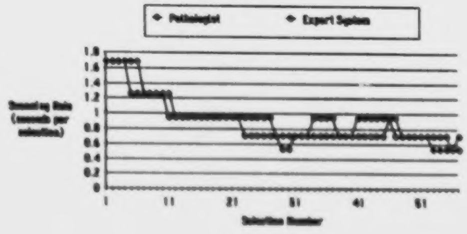
(b) Videotaped client #2



(c) Non-videotaped client #1



(d) Non-videotaped client #2



DISCUSSION AND CONCLUSIONS

The overall accuracy rate of 83.2% is quite good for an expert system. It has been proposed that an upper bound for accuracy of expert systems in which multiple experts were consulted during development may be only 75% (6).

The technique of expert system development proved to be successful in the design of an adaptive scanning technique in that the algorithm fulfills the three criteria set for it: it is transparent to the user, it constantly monitors the user's performance and sets scanning rates accordingly, and its success thus far has been objectively measured.

ACKNOWLEDGMENTS

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A Line of Gaze Communication System

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ABSTRACT

A communication system based on visual gaze has been developed. Its three distinguishing features are: 1) it allows the user to move his head freely; 2) it has a 360 degree range of measurement; 3) It is based entirely on commercially available hardware. This paper presents the hardware and software components of the system and describes the techniques used to coordinate these components.

INTRODUCTION

For many individuals, selection based on eye gaze remains a promising but largely un-fulfilled interface method. Ocular interfaces are based on the measurement of a user's gaze with respect to a target array. The measurement of gaze position is extremely complex when compared to other interfaces such as head pointing or joystick operation.

The measurement of gaze has been successfully used in a variety of other settings primarily because the design constraints for systems are less severe when compared to rehabilitation applications (6). For example, in psychological research (the dominant application for gaze measurement devices), subjects use the system for relatively short periods of time, and can cope with mild discomfort. In addition, psychological research instruments sometimes consist of a whole room of equipment.

The application of gaze measurement to rehabilitation applications such as augmentative communication systems dictate a unique set of design criteria.

Real time operation The system must be capable of measuring eye position in real time.

User comfort The user of an eye gaze communication system will in theory be using it for most of his/her waking hours. The system should not pose any discomfort and should be as unobtrusive as possible.

Moderate cost Because this application is for an individual user, the system cost must be moderate.

Relative portability Although the ideal device would battery operated and small, this is not possible with some of the technologies currently being investigated The system should be relatively portable, roughly the size a desktop unit.

Accuracy The efficiency of an eye gaze system is primarily determined by the measurement accuracy. While a system that can measure two different gaze positions could be used with a coding strategy, it is desirable to have enough targets to allow direct selection.

REVIEW OF CURRENT TECHNOLOGIES

There are two major approaches currently being used for eye gaze based communication systems. It is most convenient to categorize them as contact and non-contact systems.

Contact systems require the user to wear some apparatus in order to operate the system. The majority of implementations utilize an eyeglass frame mounted sensor that determines the position of the corneal reflection (3,5). In addition to measuring the position of corneal reflection, some technique for compensating for head movement must be used.

Non-contact systems measure gaze position with a remote video camera (4,2). These systems use the corneal reflection-pupil center method of measurement. This method uses the relative difference between the corneal reflection and the center of the pupil to determine the user's gaze.

In contrasting the two techniques, the non-contact approaches seem to offer the user a much more acceptable arrangement. Since no apparatus is worn, these systems are aesthetically acceptable and theoretically offer the user no discomfort. In reality, comfort is an issue with the current implementations because severe constraints are placed on allowable head movement. Because the video camera must image a very small area of the face to determine the relative positions of the pupil and corneal reflection, slight head movements may cause the camera to lose its view of the eye and render the system inoperable.

This design limitation is also reflected in the accuracy of such systems. By expanding the camera's field of view, larger head movements are allowed. But this is done at the expense of the system resolution and results in a smaller number of selectable targets. Contact systems do not have this tradeoff because the sensor is mounted on the head. This means that the system resolution is primarily determined by the accuracy of the sensors.

THE LINE OF GAZE SYSTEM

The Line of Gaze system is a contact gaze measurement system intended for use as an augmentative communication aid and for other control applications. Its operation is based on the measurement of eye position using the corneal reflection method and head position measurement using a Polhemus 3 space tracker. These two measurements enable the system to determine the user's visual gaze. The system has the following features:

- Because the sensors are mounted on eyeglass frames, the user's head movement is unconstrained.
- The head position sensors have an unlimited range of measurement for orientation.
- The electronic components of the system are all based on commercially available hardware. This should keep the cost moderate.

Figure 1. shows a block diagram of the line of gaze system. The system is made up of two major sensing hardware components and two major software components.

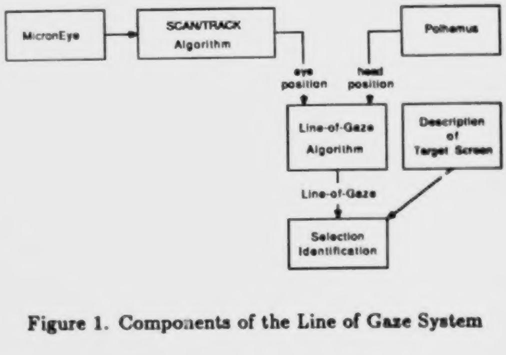

Figure 1. Components of the Line of Gaze System

Eye Position Measurement
The sensor that is being used to determine the position of the corneal reflection is the MicronEye manufactured by Micron, Inc. This sensor is a 64k RAM chip with a quartz lid. Each bit of memory provides a photo sensitive pixel. Because of the chip geometry, the effective resolution for the MicronEye is 128 by 64 which is sufficently accurate to determine corneal reflection within .5 degrees. The MicronEye is provided with an interface board for IBM PC compatibles.

Software has been developed to process image data to calculate the x and y coordinates for the corneal reflection (1). This software uses an algorithm called SCAN/TRACK that provides real time corneal reflection position. In the current configuration an IBM PC is dedicated to this subsytem. Software has been written that sends xy coordinates to an IBM AT via an RS-232 link.

Head Position Measurement
The position and orientation of the user's head is determined with a Polhemus 3-space tracker. This device measures the position and orientation of a 2 cm cube with respect to a larger stationary cube. It is a stand-alone system that sends positional information to the IBM AT via an RS-232 link. The Polhemus measures 6 degrees of freedom (3 positional and 3 angular) using electromagnetic field technology.

Line of Gaze Determination
The line of gaze is determined by an IBM AT that receives information from the two measurement subsystems. The line of gaze algorithm has been developed in the C language and serves as a device driver for the REC's communication programs.

Part of the user operation is an initial calibration procedure. This procedure maps the xy coordinates of the corneal reflection data to the actual angular displacement of the eye. A cursor appears in the four corners and the center of the display. The user must look at the cursor as it appears. Data is recorded and calibration constants are calculated. After this calibration is performed, the system is operational as a control input. Line of Gaze data is mapped against the display array and selections are made when the user fixates on an item for some programmable dwell time.

THEORETICAL CONSIDERATIONS

Figure 2. shows a geometric representation of the line of gaze system. It is important to first define the three coordinate systems that exist in the system. XYZ is the coordinate system of the world, with origin at the center of the Polhemus source. The target array is defined as the plane X = 0 in this world coordinate system. The XYZ' coordinate system is located at the center of the Polhemus sensor. This "primed" system is a straight translation of the world coordinate system. The orientation of the sensor is described by the three angles (Ψ, Θ, Φ). These angles define the third coordinate system, XYZ'', which is a pure rotation of XYZ'. The center of the eye is located at $<a,b,c>''$, a constant distance away from the origin of XYZ''.

The line of gaze vector is described as the vector originating at the center of the eye P_1 ($<x_1, y_1, z_1>$), and passing through the point P_3 ($<0, y_3, z_3>$ on the display plane, where both points are referenced to the XYZ origin. The basic technique for determining line of gaze is to evaluate P_3 based on the position of the eye P_1 and another point. This point, P_2 ($<x_2, y_2, z_2>$), is the intersection of the LOG vector with a projected plane that represents the imaging array. It is determined by the imaging array data that is mapped into the XYZ'' coordinate system based on an initial calibration, then transformed into the XYZ coordinate system.

Once points P_1 and P_2 have been determined, the line of gaze point P_3 can be found by writing the equation of the line $\overline{P_1P_2}$ and finding the intersection of that line with the plane $X = 0$. Therefore, the line of gaze point is defined as:

$$y_3 = \frac{-x_1(y_2 - y_1) + y_1}{x_2 - x_1} \qquad z_3 = \frac{-x_1(z_2 - z_1) + z_1}{x_2 - x_1} \qquad (1)$$

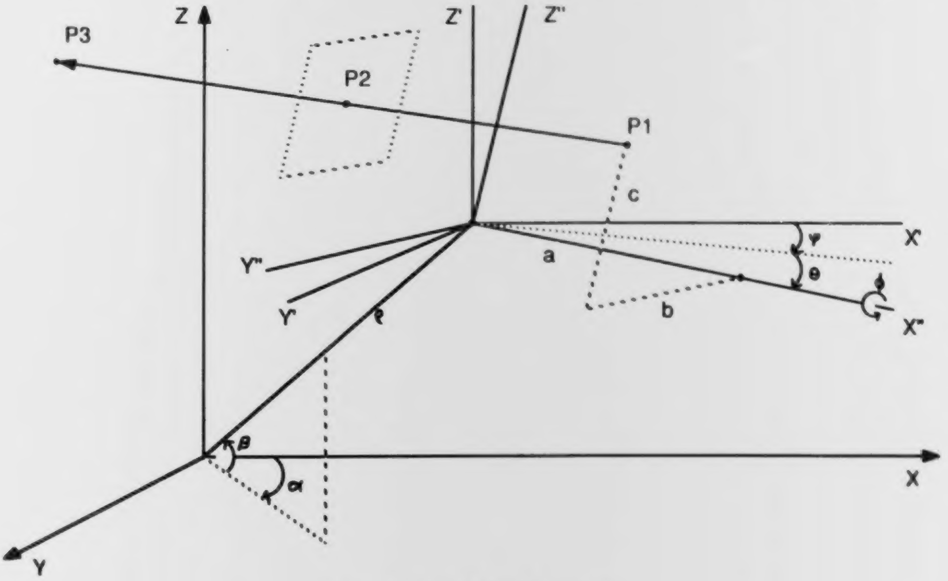

Figure 2. Line of Gaze Geometry

where:

- All points are with respect to XYZ
- $< x_1, y_1, z_1 >$ are the coordinates of the center of the eye
- $< y_2, z_2 >$ are functions of image data based on an initial calibration
- x_2 is an constant set at calibration

Both P_1 and P_2 are originally measured with respect to XYZ'' and must therefore be transformed into the XYZ coordinate system to be used in the above expression. This can be done relatively easily through a series of coordinate transforms. The steps required to do this are outlined below.

Determination of Eye Center

In the XYZ'' coordinate system, the center of the eye is located at $< a, b, c >''$ (P_1''), a point which can be measured. This can be transformed into the XYZ' coordinate system using the rotational matrices defined by the angles (Ψ, Θ, Φ). In general, then,

$$< x, y, z >' = R_z(\Psi) R_{y'}(\Theta) R_{x''}(\Phi) < x, y, z >''$$

where

$$R(\Psi) = \begin{vmatrix} \cos\Psi & -\sin\Psi & 0 \\ \sin\Psi & \cos\Psi & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

$$R(\Theta) = \begin{vmatrix} \cos\Theta & 0 & -\sin\Theta \\ 0 & 1 & 0 \\ \sin\Theta & 0 & \cos\Theta \end{vmatrix}$$

$$R(\Phi) = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi \\ 0 & -\sin\Phi & \cos\Phi \end{vmatrix}$$

For the specific case of $P_1'' = < a, b, c >''$, the result of this matrix multiplication is:

$$\begin{aligned} x_1' &= a\cos\Psi\cos\Theta + b(\sin\Phi\cos\Psi\sin\Theta - \sin\Psi\cos\Phi) \\ &\quad -c(\sin\Psi\cos\Phi + \cos\Psi\sin\Theta\cos\Phi) \\ y_1' &= a\cos\Theta\sin\Psi + b(\cos\Phi\cos\Psi + \sin\Phi\sin\Psi\sin\Theta) \\ &\quad +c(\sin\Phi\cos\Psi - \sin\Psi\sin\Theta\cos\Phi) \\ z_1' &= a\sin\Theta - b\sin\Phi\cos\Theta + c\cos\Phi\cos\Theta \end{aligned}$$

The transformation of P_1' into the XYZ coordinate system is a simple translation, so the distance between the two coordinate systems (i.e. between the Polhemus sensor and the Polhemus source) can be directly added to P_1'. So

$$< x_1, y_1, z_1 > = < x_1, y_1, z_1 >' + < x_0, y_0, z_0 >$$

where:

$x_0 = \rho\cos\alpha\cos\beta$
$y_0 = \rho\sin\alpha\cos\beta$
$z_0 = -\rho\sin\beta$

Determination of P_2

The determination of P_2 ($< x_2, y_2, z_2 >$) is simply a matter of applying the transformations described above to P_2'' ($< x_2, y_2, z_2 >''$). However, finding P_2'' is not as simple as the straightforward measurement used to find P_1''. To determine P_2'', it is necessary to use image data received from the MicronEye. Raw MicronEye data is in the form of a (y, z) pixel position in the memory array. This pixel data must be mapped into the XYZ'' coordinate system through a transformation whose constants are determined by an initial calibration. For example, using a linear transformation,

$$y_2'' = k_1 y_2^p + k_2 \qquad z_2'' = k_3 z_2^p + k_4$$

where:

- (y_2^p, z_2^p) is the pixel position of the corneal reflection,
- k_1, k_2, k_3, k_4 are constants provided by an initial calibration.

To perform the calibration, targets with known $< 0, y_3, z_3 >$ positions are presented on the screen. Because $< x_1, y_1, z_1 >$ and $< y_2^p, z_2^p >$ are known, and x_2 can be arbitrarily set, the k constants can be calculated with a minimum of two target points. x_2 can be arbitrarily set because it is the position of a projection of the actual imaging array plane, and it is used by both the calibration and LOG calculations. Although a linear mapping has been presented for simplicity, a non-linear mapping transformation is used to achieve greater accuracy.

Once P_1 and P_2 have been determined, the final coordinates of the Line-of-Gaze intersection with the target plane are determined by substituting these values into equation (1).

FURTHER WORK

The described system will be undergoing laboratory evaluation followed by a clinical evaluation. The results of these evaluations will be design revisions. The final stage of this project will be an attempt to commercialize the line of gaze technology.

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LEXICAL PREDICTION TECHNIQUES APPLIED TO REDUCE MOTOR REQUIREMENTS FOR AUGMENTATIVE COMMUNICATION

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ABSTRACT

This paper presents an experimental model for a communication system that reduces the number of keys to represent the alphabet from 27 to 11. The proposed keyboard employs nine keys which each represent a cluster of three letters, a tenth key dedicated to the space, and an eleventh used for error correction. The model uses fourth-order transitional probabilities to disambiguate among the characters of the three letter clusters. The model has been evaluated with several arrangements of letters against several texts. Measures are presented for the performance of the model in terms of the average keystrokes per letter and percentage correct prediction.

INTRODUCTION

The effectiveness of any communication system is largely dependent upon the interface between the user and the device. If the motor requirements of a communication aid can be reduced while not significantly increasing the number of keystrokes or access time, improvements can be made in the performance of the user/device combination.

This can be seen in the performance of users of direct selection communication aids when the rate of output is limited by either key selection accuracy or range of motion. Such interface difficulties exist in systems using manual, head position, and eye gaze selection techniques. While the direct selection of characters maintains a rate of one keystroke per character, the accuracy and range requirements often add excessive time to each keystroke as well as cause a large number of selection errors.

Quite often the combination of keystroke time and errors results in the use of coding or scanning systems that place less demand on the user's ability to reach a minimum of 27 keys. However, both of these approaches reduce the number of keys required to operate the device at a cost of requiring additional keystrokes.

The model proposed in this paper proposes to reduce the number of keys for direct selection typing from a minimum of 27 (a-z, and 'space') to 11. In order to offer the small number of keys and allow access to the entire alphabet, each key must represent several letters. Since the user makes a potentially ambiguous selection, provision must be made for disambiguation among the possible characters.

BACKGROUND

Witten [5] and Minneman [4] describe several multikey disambiguating schema that has been used with touch-tone keyboards. The standard 12 key telephone touch-tone keyboard has 24 characters shown on 8 keys (Figure 1.). In a representative system described by Witten, the missing characters ('space',q, and z) are assigned to the '1' key. The non-character keys (*,operator, and #) are used to disambiguate the letters. Thus the keystrokes '*2' produce 'a' and '#2' produce 'c'. This method requires two keystrokes per character for every letter entered. Witten proposes an alternative procedure that reduces the number of keystrokes per character. He points out that while each keystroke on such a keyboard is potentially ambiguous, the combination of several keystrokes limits the confusion. The touch-tone keystroke combinations for the first 50 five letter words of an English dictionary generate unique combinations for all but two of the words. In a more extensive study, Witten has shown that out of 24,500 words, 92% were defined by unique key combinations.

Minneman[4] has provided a more comprehensive model which incorporates a dictionary as well as a table of transitional probabilities. Minneman's system requires one keystroke per letter. The 'space' is uniquely defined as the 'operator' key. Since 'space' is typed unambiguously, the system knows the boundaries of each word. By consulting its dictionary, and using trigram based transitional probabilities, the system generates the most likely word that can be made from the combination of keystrokes. This is in a sense word prediction, since the system must wait until all of the keystrokes have been entered for a word.

qz 1	abc 2	def 3
ghi 4	jkl 5	mno 6
prs 7	tuv 8	wxy 9
*	O	#

figure 1.

Conventional Touch-Tone Keyboard with 'q' and 'z' added

CHARACTER PREDICTION

The model presented in this paper deals with the use of fourth order (quadgram) transitional probabilities to predict the correct letter without benefit of a dictionary. The proposed method uses a keyboard which devotes 9 keys to the alphabet, one key to the 'space', and one to an error correction feature.

As the user types a single key, the system will determine which of the three characters on that key is most likely, based upon the probabilities of each of the three letters following the three previously typed characters. If the device predicts the correct character, the user types the next letter of the word. If the prediction is incorrect, the user can select the next most likely letter by entering the error key. A second selection of the error key chooses the third most likely character. In this system, character selections require 1, 2, or 3 keystrokes. Since the disambiguation is performed statistically, it is expected that the majority of predictions will be correct and that the communication system will approach 1 keystroke per character.

STATISTICAL BASE

The statistical base used in this model is a table of quadgrams that has been generated from the Brown Corpus.

The Brown Corpus consists of approximately 1 million words of English text representing a range of sources which include newspapers, novels, and scholarly works.(Kucera and Francis[2]). The quadgram table was produced for this project by means of an exhaustive count of all four letter combinations that occur in a filtered version of the Corpus. The filtering was used to eliminate nonstatistical information from the Corpus such as upper vs lower case, multiple spaces, and nonalphabetic characters. The filtering reduced the Corpus to approximately 750,000 characters.

The project is also concerned with the development of a Dutch language version of the communication system. A similar quadgram table has been developed using the Eindhoven Corpus which has approximately 1 million words of combined Dutch written material and transcribed speech.

EVALUATION OF THE MODEL

Alphabetic Keyboard

The model has been evaluated by examining its ability to predict characters of known texts presented in an error free manner (text file read by microcomputer). The keyboard was modified slightly from the telephone touch-tone design. The order of the alphabet was restored by placing 'abc' on key 1, 'def' on key 2, ... and 'yz' on key 9.

The model was run with English quadgrams using a 32,801 character text that was a subsample of the Brown Corpus. The model was run with the Dutch quadgrams using a text of 31,657 characters taken from the Eindhoven Corpus. The percentages of correct predictions are shown in table 1.

Language Model	Correct Predictions
English	88.2%
Dutch	87.5%

Table 1. .....

The keystrokes per character including the additional keystrokes required for the second and third choices are English 1.14 keystrokes/char. and Dutch 1.15 keystrokes/char. This compares very favorably to the 2 keystrokes/char. required by the multikey procedure using the *0# keys for disambiguation.

Optimized Keyboards

Among other information derived during the evaluation of the model was a count of errors attributed to individual characters. From this data it was possible to make intuitive modifications to the character assignments on each key in order to reduce the number of errors. By example, the 't' was observed to be in conflict with the 's' and 'u'. Moving the 't' to key 8 with the 'y' and 'z' resulted in an increase in correct prediction to 90.2% for the same English text sample. The additional exchange of the 'o' and the 'j' increased the prediction to 90.4%. Further improvement to 90.8% was made by exchanging the 'c' and 'x'(Figure 2.). In this evaluation the second choice prediction was correct 7.6% and the third choice was correct the remaining 1.6%. This results in rate of 1.11 keystrokes/char. This modified TOC keyboard (since the 't','o', and 'c' were moved) appears to spread prediction errors nearly evenly among the eight character keys. This intuitive letter assignment was not done for the Dutch keyboard, however, it is likely that similar improvements can be made.

Levine et al [3] have proposed a method of deriving character groupings using a computer optimization algorithm that minimizes inherent ambiguity. Using this method, with the number of characters per key constrained to 3, an optimized keyboard was designed (Figure 3). Evaluation of this keyboard with the same sample English text shows a prediction rate of 90.8%. This is the same as the TOC keyboard.

abx 1	def 2	ghi 3
okl 4	mnj 5	pqr 6
su 7	vwc 8	yzt 9
* cor	0 space	#

Figure 2.

TOC Keyboard superimposed on Touch-Tone Keypad note the addition of the 'space' and 'correct' keys

dcl 1	mpo 2	ejb 3
knw 4	fgs 5	huy 6
izr 7	va 8	txq 9
*	0	#

Figure 3.

One of Levine's Computer Optimized Keyboards

Effects of Text Samples on Prediction Performance

The question of the effect of different text samples on the performance of the TOC keyboard was addressed by evaluating the model with four additional English text samples. These were: a second 37,764 char. taken from the Brown Corpus (Brown 2), a 56,730 char. passage of Carterette's (Carterette[1]) transcribed first grade child conversations (Carterette Child), a 47,993 char. sample of Carterette's (Carterette[1]) transcribed adult conversations (Carterette Adult), and a 56,141 char. recent engineering grant proposal from the first author (Foulds Grant). The prediction results are summarized in table 2.

Text Sample	Correct Predictions
Brown 2	90.8%
Carterette Child	87.6%
Carterette Adult	89.2%
Foulds Grant	90.4%

Table 2. .....

The percentage of correct prediction remain reasonably constant for the three text samples drawn from adult material, and drops only slight for the transcribed child speech. This indicates that the quadgram table produced from the Brown Corpus is useful for a wide range of English.

DISCUSSION

Consideration of errors

The question arises as to why the optimized keyboard generated by Levine's algorithm does not show an improvement over the intuitive TOC keyboard. The answer to this appears to be found in the analysis of the prediction errors. In all evaluations of the TOC keyboard and Levine's keyboard, and for all text samples, 55-60% of all prediction errors occurred on word initial letters. The transition between words renders the use of quadgram statistics considerably less useful at word boundaries. One may assume, therefore, that there will be an uncertainty associated with the word initial letter that is relatively uneffected by the use of the quadgram table and the optimization of the keyboard. If this is the case, then 96% of the system performance is accounted for by the correct predictions (90.8%) and the word initial errors (9.2% x .6).

Mental Load

A communication system based on this model will offer a keystroke/character measure that approaches that of a 27 key device. Certainly, in terms of the accuracy and range requirements as well as the keystrokes/character this method has interesting potential. The primary possible drawback stems from the inaccuracy of the predictions. Although the accuracy is high, there remains the possibility that the prediction will be in error. The extent to which these errors effect the operation of a device by a user has not yet been determined.

The mental load placed on the user to monitor each character selection for correct prediction will undoubtedly be higher than the mental load required by a conventional direct selection system. The effect of this additional load on the user's performance will be measured experimentally in a later phase of this project. The effect is likely to be somewhat reduced by the fact that 60% of the errors occur on word initial letters, thus forewarning the user to give more attention to that situation.

Size of the Quadgram Table

In order to transform this model into a clinical communication aid, attention must be given to the size of the quadgram table. The use of 30 characters (26 letters, 'space', 'period','question mark', and 'exclamation') produces a possible quadgram table size of 810,000 entries. In fact, the table generated from the Brown Corpus has only 53,423 quadgrams with an occurrence greater than 0. If the table is limited to quadgrams with occurrences greater than 10 the total drops to 19,400. The number of quadgrams which occur greater than 20 times is 14,761.

An evaluation was performed on the effect on prediction in the model if reduced tables were used. Using the same 32,801 character sample from the Brown Corpus, the table with greater than 10 occurrences accounted for 97.8% of all quadgrams used in the prediction, while the greater than 20 table accounted for 96.5%. A modified version of the model substituted simple monogram frequencies (rank order) for quadgrams that were not included in the reduced tables. The prediction percentages for the TOC keyboard using the reduced quadgram tables are compared with the complete table in table 3.

Quadgram Table	Correct Predictions
Complete Table	90.8%
Greater than 10 table	90.4%
Greater than 20 table	90.0%

Table 3. .....

Further Work

This project is a collaborative effort between the Rehabilitation Engineering Center at Tufts University/New England Medical Center and the Institute for Rehabilitation Research in the Netherlands. Work will continue on refining the model for both English and Dutch and will lead to clinical experimentation that will examine the effects of mental load on the users of such a communication aid.

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SEMANTIC COMPACTION FOR SUB-SENTENCE VOCABULARY UNITS COMPARED TO OTHER ENCODING AND PREDICTION SYSTEMS

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ABSTRACT

Earlier writings about semantic compaction have focussed on its ability to represent sentences. This paper will concentrate on sub-sentence vocabulary units (words and phrases) and compare the efficiency of the semantic compaction technique with stenotype (machine shorthand), abbreviation systems, and word (or linguistic) prediction systems. Semantic compaction will be found to be more efficient than any of the preceding systems in terms of the number of actuations per word. The performance of semantic compaction will be discussed relative to human factor issues and problems inherent in abbreviation and word prediction systems.

INTRODUCTION

Semantic compaction is a technique that employs icons as code elements to describe entities in any relational data base. This technique has been primarily developed for encoding language units in dedicated systems designed for people with physical and cognitive disabilities which render communication difficult. The technique has been called semantic compaction because it allows the user to impute many different meanings to a single icon. Which meaning is active in the icon is determined by the context in which the icon is used. Such a system is commercially available from the Prentke Romich Company under the name Minspeak™.

Because this technique was developed for people with physical disabilities which made activating any kind of switch difficult, semantic compaction was usually described in relationship to whole sentences: the larger the vocabulary unit accessed, the greater the efficiency obtained. In short, if 3 actuations produce an appropriate sentence rather than just an appropriate word, people with severe physical impairments would be able to communicate in a more timely fashion. Much effort was devoted to establishing core sentence vocabularies.

Many users achieved great efficiency and communication enhancement through using sentence-oriented vocabulary systems. No linguistic corpus, however, made up solely of sentences was able to provide the total flexibility that is needed for everyday life. Educated users often found themselves spelling out, letter by letter, substantial portions of their daily communications. This fact led to the development in 1984 of vocabulary organizations designed to give users access to words and phrases as well as sentences by means of sequenced icons.

Using syntactically oriented labels as elements in a sequence is one method of using polysemous (multi-meaning) icons to represent words and phrases. An icon sequenced with the label **Noun** would mean something very different from that same icon sequenced with the label **Verb**. The icon of a house when sequenced with **Verb** could mean "live" but when sequenced with **Noun** could mean "home". With **Preposition** the same icon could mean "inside"; with **Adverb** it could mean "here".

Many such systems have been successfully implemented at a variety of sights. One user who was spelling on a letter-oriented communication system began in August of 1986 to use polysemous icons sequenced with syntactic labels. In a six-month period, this user went from a position of spelling nearly 100% of his utterances to a point where he now spells out fewer than one word in 25. The average length of a word in English is about 6 characters (including space), and the average length of an icon/syntax label sequence is between 2 and 3. The savings using sequenced icons on words alone is over 50% as compared to spelling. This, however, is only part of the total savings.

Semantic compaction easily represents the many collocative phrases that make up a substantial portion of daily language, and it is able to represent these phrases by sequences composed of only 2 to 3 elements. A collocation is 2 or more words which occur together. There are many different kinds of collocative phrases. Article-noun collocations are quite common, for example, *the book*. But collocative verbal phrases constitute nearly 20% of daily speech. These phrases are made up of the subject personal pronouns and demonstratives (*I, you, he, she, it, we, they; this, that, these, those*) combined with the modals, auxiliaries, and semi-modal phrases that serve to introduce verbs both in speech and in writing.

The nine common modals in English are: *shall, will, can, may, must, should, would, could, might.* The auxiliaries are: *to be* and its forms (*am, are, is, was, were, be, been*) and *to have* and its forms (*have, has, had*) as well as *to do* and its forms. The modals combine with the personal pronouns and demonstratives in the ways summarized here using *would* and *he* only:

he would	*would he*
he wouldn't	*wouldn't he*
he would be	*would he be*
he wouldn't be	*wouldn't he be*
he would have	*would he have*
he wouldn't have	*wouldn't he have*
he would have been	*would he have been*
he wouldn't have been	*wouldn't he have been.*

The auxiliary forms combine with the personal pronouns and demonstratives in the ways summarized here again using only *he* :

he is	*is he*	*he isn't*	*isn't he*
he was	*was he*	*he wasn't*	*wasn't he*
he has	*has he*	*he hasn't*	*hasn't he*
he has been	*has he been*	*he hasn't been*	*hasn't he been*
he had	*had he*	*he hadn't*	*hadn't he*
he had been	*had he been*	*he hadn't been*	*hadn't he been*
he does	*does he*	*he doesn't*	*doesn't he*
he did	*did he*	*he didn't*	*didn't he*

When the preceeding synopsis is expanded by all the subject pronouns and demonstratives through all the modals and auxiliaries the quantity of different forms is enormous (more than 500). And, as repetitive as the elements of this list may seem, they are the cement that holds the language together. Semantic compaction is capable of representing each of them in a short (the majority require only one icon and one label) unique sequence that is easy to understand and easy to recall.

Another category of frequent collocations comprises compounds of personal pronouns and demonstratives with semi-modal phrases. English is rich in phrases which have modal force. For instance, *used to* signals discontinued progressive action in the past. Other languages use tense endings to express the same idea. *Have to* can replace the modal *must*. *To be going to* regularly replaces the modals *will* and ***shall*** in daily speech. The foregoing three constructions are examples of a type of common locution that proliferates to form an entire complex of words which consistently follow each other. A synopsis of *used to* and *he* is represented here: *he used to, did he use to, he didn't use to, didn't he use to*. Again as with the modals themselves, semantic compaction easily represents semi-modal phrases with short icon/syntax label sequences.

Thus while the use of polysemous icons can result in a savings of more than 50% over spelling when used for words, when used with the various collocations with which English is rife, the savings are even greater. For instance, *haven't they been* requires 17 characters when spelled but is represented by a sequence of 2 icons and 1 label. As specific examples will demonstrate later on in the paper, the semantic compaction technique offers its users reductions ranging between 65% and 80% for the generation of novel text based on a user specific vocabulary of approximately 2,800 entries.

MACHINE SHORTHAND

Describing how the savings obtained by semantic compaction over traditional orthography compares with other techniques is the express purpose of this paper. The first technique to be compared to semantic compaction is that of stenotype or machine shorthand. Many people assume that machine shorthand, because it is used in court reporting, must give its users an advantage over typing owing to a reduction *vis-à-vis* spelling in the number of actual selections to be made. The situation is, however, not quite that simple. Machine shorthand is based on syllables and the fact that able-bodied people have 10 not 26 fingers. For instance, the only vowels on the machine are **a**, **e**, **o**, and **u**. There is no **I** because the thumbs activate the vowels which are on two keys placed in positions under each making it easy for the thumbs to activate them. The vowel I is made by activating **e** and u simultaneously with the right thumb. The combination **eu** designates I.

Another example is the letter **n** which is not represented on the keyboard by any single key but rather is signaled in two distinct fashions: to initialize a syllable with **n** requires the user to strike **tph**; to use an **n** after a vowel requires the user to strike **pb**; **m** initializing a syllable is represented by **ph**; followed by a vowel it is represented by **pl**.

The foregoing strategies are effective for able-bodied individuals because of the fluid motion of their fingers on a specially constructed keyboard which represents all 26 letters and 10 numbers by only 24 keys arranged in such a way that simultaneous double activations by single fingers can be made consistently enough to describe all possible syllables in English. If this technique is translated directly for a single key actuating user, the result is more actuations than with ordinary spelling. Court reporters use not only the machine notation but employ within it a complex system of "brief forms" which takes years to implement and perfect. These "brief forms" are quite complex and depend upon a thorough knowledge of syllabic writing. The brief form for *mechanic* phonetically is "mek" but is actually written by striking **pl e bg**. The brief form for *mechanical* is "mek al" which is written by actuating **pl e bg al**.

Machine shorthand unaided by "brief forms" requires more actual key depressions than traditional orthography. The system depends for its great efficacy in transcribing speech upon the able-bodied stenographer's ability to describe each and every syllable or "brief form" by a single "lunge" of his or her hands striking approximately 4 to 7 keys with each "lunge".

ABBREVIATION

Another form of rate enhancement to be compared to semantic compaction is that of abbreviation expansion. There are several different expansion techniques but for the purpose of this paper no one of them in particular will be discussed in great detail. Instead the technique in general will be summarized. Abbreviation expansion is when a reduced number of elements of a longer representational form are expanded (often automatically) by a computer to that longer form. For instance, one could set up a system whereby spelling "prdctn" and a "space" would produce "prediction" on the display .

There are several problems with this technique, but the brevity of this paper allows commenting only upon the most salient ones. First, conflicts arise among the reduced forms. For instance, in the preceeding example, the reader may well have read "prdctn" as *production* rather than *prediction*. Does "wk" mean *week, weak, work*, or *walk?*

In order to distinguish among these words other letters have to be used either making the abbreviation longer or distorting it. For instance, *week* could be represented by "we", *weak* could be represented by "wa" and *walk* could be represented by "wl". If "we" represents *week* how does one represent the first person plural pronoun *we* ? How does one represent the common adverb *well* ? How does one represent *will* ? If one uses "wa" to represent *walk* so that "wl" can be free for *will*, then how does one represent *want* or *was* ? Soon a letter not in the word is going to have to be used or three letters are going to be required to give a unique form for each of these common four-letter words. This is just the tip of the iceberg. After a substantial number of entries has been made, it can become difficult to have the shortened form even "look like" the expanded form.

One widely described abbreviation expansion system recommends the following abbreviations in its treatment of 150 commonly occurring words:

about	; _(_means space)	*help*	hp
all	:_	*hope*	ho_
do	d_	*how*	w/
don't	e_	*why*	y/
does	ds	*happy*	hy
didn't	dd7	*week*	wk_
get	v_	*work*	wk
give	gv	*were*	wr
going	gg	*write*	wrtu

Within the first 150 words the problems with abbreviation systems that were noted earlier have already appeared. Characters not in the original spelling have begun to be used, the "u" in write being an extreme example. Note as well the "abbreviations" that bear little resemblance to the spellings in traditional orthography. One also wonders how to abbreviate *giving* or *getting* when *going* is abbreviated "gg". When such a system expands to include many hundreds of entries, the complexities multiply dramatically.

In principle, an abbreviation system could achieve the same reduction (about 65-80%) over spelling that semantic compaction does if it were extended over a relatively large number of words (700-1000). A wide extention of this technique, however, results in such an arbitrary and confusing set of codes that its utility would be highly suspect.

WORD PREDICTION

Word prediction is a technique that "fills in" after enough information has been given. For instance if "bo" were typed the system would expand to "book" or display a menu of words from which to choose, such as "boy", "boat", "both", "boldly", etc. Sometimes both these strategies occur simultaneously. The user then accepts the suggested word by entering "space" or selecting a number on the keyboard which corresponds to a number on the word menu.

Linguistic prediction is word prediction which take into account syntactic information. For example, in the last paragraph, 4 possible "fill in" items were listed. If the sentence were, however, *I saw the . . .* , the words *both* and *boldly* could not syntactically fit in the slot following *the*. A linguistic predictor would not list *both* and *boldly* because it knows that *the* places selection restrictions upon the item following it that exclude adverbs (*boldly*) and conjunctions (*both*).

The immediate disadvantage of word and linguistic prediction techniques is that the user must constantly be reading menus; his or her eyes and attention shift back and forth between the keyboard and the display. The user is steadily being presented with words that it was not his or her intention to write or utter. This kind of enforced reading is the linguistic equivalent of scanning. A feeling of transparency (being able to focus on *what* you are saying rather than *how* you are saying it), so important in the successful use of any writing or communication aid, is difficult if not impossible to develop.

It is just this kind of transparency that is achieved using semantic compaction. Many users report that they no longer think of the icons on a semantic compaction system. Their eyes and minds seem to process the pictures nearly subliminally; this probably occurs through the agency of some process related to recognition memory. Thus the difference in terms of ergonomics between semantic compaction and word/linguistic prediction systems is that the former gives free and uninterupted direct linguistic selection and the latter interrupts the user's train of thought with the necessity of changing mental processes from language production to reading, and making selection and rejection judgements.

In terms of efficiency, semantic compaction offers significant advantages over word prediction techniques. The following analysis can serve as representative of the results of counts done on a large number of sentences. The sentence was chosen because it was typical of colloquial English and relatively short.

She called when she could.

The sentence has 25 letters and spaces, final punctuation not being counted. In a word prediction system which has syntactic knowlege and which could be called a linguistic prediction system, approximately the following would happen: *She* - 1 stroke needed for "S". "She" would be among the menu choices (approximately 7 items.) A space or a number would be required; thus 2 strokes would be necessary for the 4 characters of "She ". The same sort of analysis would say that *called* would require 3 letter selections: 1 for "c", 1 for "a" , and 1 for "l". At "l" the system would produce "called" as one of its menu choices, thus requiring 1 more stroke for selection. All together 4 strokes for *called*.. *When* requires 4 strokes on one widely discussed word prediction system. So many words begin with "whe-" that several menus are needed. *She* would again require 2, and *could* needs 3: 1 for "c", 1 for "o", 1 for selecting the word from the menu. 15 strokes in all are required by a word prediction system to produce the above sentence of 25 characters.

With semantic compaction 2 strokes are required for *she* . 3 strokes are required for *called*. 2 strokes are needed for *when*, and 2 are needed for *she could*. Semantic compaction thus requires a total of 9 strokes.

The figures cited throughout the paper are general and should not be overinterpreted. They are for purposes of comparison. However, they *are* representative of the comparative strengths and requirements of the various systems mentioned. Semantic compaction clearly requires fewer actuations, and is linguistically more transparent and productive than machine shorthand, abbreviation techniques, or word prediction systems.

EXPLOITING WORD FREQUENCIES AND THEIR SEQUENTIAL DEPENDENCIES

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ABSTRACT

A word/phrase anticipatory aid exploiting the redundancy of a language is currently under development for use within a workstation for the severely motor impaired (6). This aid uses not only the frequency of occurrence of individual words in the language, but also knowledge of their sequential dependencies.

INTRODUCTION

By taking advantage of the redundancy of a language, one can predict the characters most likely to follow a given set of input. This is particularly useful in developing communication aids designed to increase both the efficiency of communication (by reducing the number of inputs needed to generate a character) and the rate of communication. Additional benefits occur as automatically generated characters/words reduce the likelihood of either spelling errors during text composition or syntactic errors in computer program coding being introduced by the user, and reduce the cognitive load required by the task of spelling.

Previous work has exploited the redundancy of the English language with considerable success. Early work encompassed letter anticipation (3), while subsequent work has addressed word anticipation (4). This current effort is an extension of these works and incorporates an *n*-th order word approximation*1* algorithm (7). Thus, in order to determine the next most likely candidates for word/ phrase completion, not only is the statistical nature of individual words considered, but also the transition probabilities between words and word phrases.

BACKGROUND

Initial work - version ALPHA

A word anticipation aid similar to that described by Gibler (4) was used as part of an initial executive workstation designed for motor impaired individuals (5). This aid was the first of several cognitive assist modules envisioned in the overall design of the workstation. The major differences between Gibler's work and this, is that the latter includes both words and commonly occurring phrases, but does not use a learning element for acquiring new words during a user session.

The ALPHA version used several dictionaries, each tailored to a specific application. A dictionary set up for the UNIX*2* operating system contained applicable UNIX entries ("setenv TERM", "ls", "logout"), while a Pascal dictionary contained keywords ("while", "until", "begin") and common variables. Text dictionaries were created for "generic" English, and context specific dictionaries for technical documents and articles dealing with international events. Context changes were noted by a state machine which controlled which dictionary to use.

Based on 63 articles (25,780 words total) dealing with world events, an "international" dictionary was created by analyzing the frequency of occurrence of individual words as well as the frequency of transitions among word sequences. This analysis resulted in: 2511 individual words, 2346 two-word phrases, 748 three-word phrases, 165 four-word phrases, 41 five-word phrases, 14 six-word phrases, and 5 seven-word phrases. The resulting dictionary contained both phrases common to most English texts and context specific phrases ("Prime Minister", "terrorist attacks").

Two problems (shown later in RESULTS) existed with this initial word completion version. First, the candidate completion words were presented in order of frequency. If the desired word was not on the list, the user was forced to search through all possible completions (eight in this version), before concluding the desired word/phrase was not present. Secondly, while the dictionaries contain frequently occurring words and phrases, the index used for dictionary look up consisted only of the most current word's partial input, ignoring any previous input. With either zero or one letter of input to use as an index, there was a very low probability of a match with the desired word completion. (A default list was provided with zero input.) Due to the system's resetting of its search space after every word was entered, the user was offered many useless candidates (e.g. "the" after an input of "the ") until several letters had been entered as new input. The result of this look up scheme was a first order word approximation system.

N-th order word approximation - version BETA

To help alleviate these problems a new version (BETA) of word completion is currently under development. To reduce the user's search time of the candidate words/phrases, the display strategy has been modified to list the candidate word list in an alphabetized alphabetized. Also the choice with the highest frequency of occurrence is highlighted.

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[1] Word order approximation deals with the relative frequency of word groupings in a language. A first order word approximation is concerned with only the relative frequency of occurrence of individual words. A second order word approximation is based upon the relative frequency of word pairs, while an *n*-th order word approximation deals with the relative frequencies of sequences of *n* words.

[2] UNIX is a trademark of Bell Laboratories.

In an effort to improve on the initial word completion utility, it was decided to modify the key/index, allowing it to grow with the input. This provides look ups based on a longer previous input, capitalizing on the word transition probabilities pointed out by Shannon. This key is used as an index into pre-computed lists containing the commonly occurring words and phrases. Matches found by the key are retrieved. If there are insufficient matches, the key is shortened by one word and more comparisons are done. This process continues until either the desired number of matches are returned, or the key is exhausted.

In an abbreviated example:

```
  User Input:  "The "
  Text Buffer: "The "
  Initial Index Key: "the "
  Retrieved potential completions:
   1. country        (from "the country")
   2. government     (from "the government")
   3. Soviet         (from "the Soviet")
   ** U.S.           (from "the U.S.")
  Final Index Key: "the "
```

(With '**' indicating the most frequently occurring phrase beginning with "the " in the dictionary.)

```
  User Input:  "S"
  Text Buffer: "The S"
  Index Key:   "the s"
  Retrieved potential completions:
   1. same           (from "the same")
   2. Soviet Union   (from "the Soviet Union")
   ** Soviets        (from "the Soviets")
   4. state          (from "the state")
  Final Index Key: "the s"

  User Input:  Word-Completion-3
  Text Buffer: "The Soviets"
  Index Key:   "the soviets "
  Retrieved potential completions:
   1. in             (from Default List)
   2. of             (from Default List)
   3. the            (from Default List)
   ** were           (from "the Soviets were")
  Final Index Key: "" (Null)
```

METHODS

Five motor-impaired users participated in the evaluation of the initial system (Test 1). During the testing of the system, one of the major tasks of the subjects was to transcribe articles. Five articles were used, all of which dealt with international events (none of the articles were used in forming the dictionary). There was a total of twenty-three transcription sessions. The users' input device was a joystick used in conjunction with an interactive display module portraying a "virtual keyboard" (2).

A second test conducted by development staff within the laboratory only, was concerned with the relationship between the utility of word completion and the specialization of the associated dictionary vocabulary. As such the emphasis was to use word completions whenever possible. The five original articles plus two new international articles and one technical article were used. In the first phase of the test (Test 2a), the articles were transcribed with their appropriate dictionary in order to examine what effect the specialized dictionaries had upon performance. To test the bias introduced by using only the appropriate dictionary with an article, the test was repeated by transcribing the international articles with the technical dictionary and the technical article with the international dictionary (Test 2b). The input device used was the keyboard, with each keypress counting as one movement.

A third test (Test 3) identical to Test 2a, except that the index used for dictionary look up was based on the longer N-th order word approximation look up key, was performed. All tests were run on an AT&T PC 6300 PLUS using MS-DOS[3] 3.1.

RESULTS

Communication Rate
(characters out / minute)

TEST	#SESSIONS	MINIMUM	MAXIMUM	AVERAGE
1	23	10.5	34.8	18.1

Communication Efficiency
(movements / character out)

TEST	#SESSIONS	MINIMUM	MAXIMUM	AVERAGE
1	23	1.59	2.38	1.98
2a	8	.54	.68	.61
2b	8	.70	.82	.77
3	8	.44	.61	.53

The results of test 1, while not entirely comparable to previous systems due to the difference in input devices (an eight direction joystick versus a two-input switch), the average efficiency rating of 1.98 movements per character compares favorably with other research efforts: Gibler's (4) 2.95, and Baletsa's (1) 3.88 and 3.12 communication efficiency scores. Subjects with the least motor impairment used word completion the least. However, these subjects were able to use the joystick input more rapidly and achieved the highest communication rate. Those with the greatest motor impairment demonstrated the highest communication efficiency (and the lowest communication rate). This tends to support the observation (3) that with individuals with a long movement time "a high degree of language anticipation should be employed".

When comparing tests 1 and 2 (multiplying test 2's efficiency by 2-2.1 to obtain comparable input devices), there is a large difference between the efficiency recorded in test 1 and the near maximum potential of word completions in test 2. There are several potential causes. In test 1, the subjects were aware of the word completion mechanism, but were not instructed to use it whenever possible. From critiques given by the subjects on the ALPHA version, they alluded to the low success rate with which the word completion system operated at the beginning of each new input word.

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[3] PC 6300 PLUS is a registered trademark of AT&T, MS-DOS is a registered trademark of Microsoft Corporation.

This could be a reason for not taking greater advantage of word completion. Another potential cause was the display strategy using frequency of occurrence to order the display. This greatly increased the search time, possibly further discouraging the users away from word completions.

The results of the in house trials (Test 2a and 2b) indicate that clear gains can be made by specialized vocabulary dictionaries. When the dictionaries were swapped, efficiency although decreased was still high. This may indicate that there is enough commonality in English that an imperfect dictionary with commonly occurring phrases can still be beneficial to the user. This may also support the contention (5) that increases in the size of the core element does not significantly affect communication efficiency.

As had been hoped, the third test using the longer key look up of the BETA version, showed an improvement of the communication efficiency in a pair-wise comparison to the results of Test 2a using the ALPHA version. These new communication efficiencies represented an improvement of 5.8% to 18.6% over the old method, with an average improvement of 12.8%.

FUTURE WORK

Additional gains may be realized from the incorporation of a short term learning element similar to that described by (5).

Diligent use of word completion will improve communication efficiency, but may adversely affect communication rate. However, for extended use, the increased communication efficiency may have a positive effect upon reducing user fatigue. This would partially negate any decrease in communication rates. Tests need to be conducted over an extended session to determine these effects.

While text composition benefits from an *n*-th order word approximation look up, it is doubtful that similar gains may be realized in smaller, more constrained languages (e.g. a programming language). Such domains may benefit more by incorporating syntactic and semantic information as part of their assist strategies, than the simpler assignment of frequencies of occurrence to words and phrases.

Tests are needed to determine if there is an "ultimate *n*" to be used for both the creation of dictionaries as well as the subsequent search through them. There is a sharp drop off at three word sequences. *N*-sequence lists exact both a heavy computational effort (one time) and storage demand (continuing). Future work will determine the effect of the *n* on system performance. Tests are also needed to see if the 500 word limit (5) on the size of the dictionary also applies to *n*-th order word approximation look up strategies.

CONCLUSION

It is clear that incorporating frequently occurring phrases into a dictionary and using longer keys for indexing into these dictionaries, that much improved communication efficiencies are realizable. Since the latest enhancement to the system, has not been used by any motor impaired subject, it remains to be demonstrated how *n*-th order word approximation look up will affect communication rates.

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THE USE OF SYNTAX IN A PREDICTIVE COMMUNICATION AID FOR THE PHYSICALLY HANDICAPPED

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ABSTRACT

PAL is a portable communication aid and keyboard emulator which offers the user complete word predictions based on previous input. With a dictionary capacity of approximately 1000 words, keystroke (or character selection) savings in the area of 50% have been obtained for text from various sources. In order to improve this further we have investigated the inclusion of syntax into the predictive system. A probability matrix for grammatical class pairs has been produced and this has been used to modify the word frequencies in the dictionary according to the syntax class of the preceeding word. In this way the predictions more accurately reflect the words which the user might require.

INTRODUCTION

The development of switch operated keyboard emulators has given many disabled people access to computerised systems and all the facilities that they offer. One of the most common input systems is the scanned matrix which allows even the most severely physically handicapped to generate text for personal communication or wordprocessing. There are, however, many users of switch input systems and standard keyboards who are being seriously limited by the speed at which they are able to generate characters, speeds of less than 10 wpm being very common. There are a number of techniques available which can give a higher rate of communication, for example, commonly used words and phrases can be stored and accessed by a code, an abbreviation, or a pictorial icon (1,2). Abbreviations and stored phrases become less useful in unconstrained conversation, and a number of systems which offer word predictions from automatically adapting dictionaries have been developed (3,4,5). One such system called PAL was developed in Dundee and is implemented on an EPSON PX8 portable microcomputer.

PAL offers the user 5 word predictions from its internal dictionary after each keypush or character selection. If the user selects a word from the prediction list it is completed automatically along with it's trailing space. Usage statistics in the form of a frequency count are maintained for each word, and these are updated each time the word is used. PAL also acquires new words as they are used hence adapting itself continually to the vocabulary of the user. Although PAL can give the user a 50% reduction in character selections when producing text we are looking for ways to increase this figure still further. One method of doing this is to include knowledge about grammar in PAL.

In natural language processing a phrase structure grammar is often used to represent the structure of language (6). This is a set of rules which specifies the structure of a sentence and the possible transitions which can exist. This approach has been used to include syntax in predictive systems (4,7), but as there is no statistical information available about the various possibilities that exist it is difficult to use it to predict correctly. The Markov model provides an alternative representation of language. At any stage in the sentence it is possible to specify a set of probabilities for the grammatical class of the next word based on the most recent past classes.

SIMULATION OF SYNTAX PREDICTION

In order to assess the effect of syntax on key saving we performed a simulation of a perfect syntactic predictor. We tagged all the words of four 3500 word texts with their grammatical classes and then used them in a text entry program. The grammatical tags caused the predictor to offer only words of that class in prediction lists, as though it had correctly identified what the class of the next word would be. This simulation yielded an increase in the key saving of approximately 10% over that given when entering the texts normally, i.e. a keysaving of 50% was increased to 60%. As we can only determine a range of probabilities of various classes which may occur after any given word these figures will be higher than can possibly be achieved in a working system, but they indicate that useful additional keysavings may result from the addition of syntax.

PRODUCTION OF SYNTAX TRANSITION MATRIX

We generated a first order syntax transition matrix by examining the word pairs in the tagged texts mentioned above (8,9). Rather than tagging the texts completely by hand in the first instance we merely tagged the dictionary and used that to tag the texts. This will have introduced some minimal errors as it is only possible to tag a word with one class. As some words in English can have several different syntactic classes in different contexts the most common class only was used. In this initial system we used 16 basic classes in order to produce a small (compact) system that could be implemented in the current generation of PAL, although in linguistic research it is more common to use a larger set (8,10,11).

INCORPORATION OF SYNTAX MAP IN PAL

PAL ordinarily compiles its prediction lists using the word frequency information in the dictionary to determine the most probable next words, i.e. those with the highest frequencies. The syntactic predictor used 'effective frequencies' which are given by:

$$F(effective) = F(W) \times P(B|A)$$

Where W is a word of syntax class B, F(W) is the actual stored frequency (word count) of the particular word, and P(B¦A) is the probability of a word of class B given that the last word was of class A. This has the effect of re-ordering the word frequencies after each word has been entered according to that words class. This approach ensures that even when P(B¦A) is a small number (very low probability) words of class B will eventually be seen in prediction lists (but maybe not until after 2 or 3 keypushes). In cases where P(B¦A) is small and F(W) for a word of class B is very large that word may appear in early prediction lists.

OBSERVED USE

As one progresses through a sentence the prediction lists are very obviously affected by the word that has gone before. This is particularly noticable after classes such as pronouns or definite articles where there is a very high probability of one particular class (P(pronoun¦verb)=0.70, P(article¦noun)=0.60).

NUMERICAL TESTS.

To assess the numerical effectiveness (increased key saving) of a syntactic predictor we used a text input program to enter three texts of 3500 words each, covering different subject areas. Albans is a lecture on TV subtitling, Times is a selection of leader articles from the Times newspaper, and News is a transcript of a television news bulletin. The texts were entered using pre-built tagged dictionaries which only contained the words in that particular text. We have not, as yet, included a mechanism for determining the syntactic class an unknown word so no unknown words are allowed. The results for the three texts, with prediction lists containing 1, 5, and 10 words, are shown below:

		Key saving %	
		No Syntax	Syntax
Albans	1	42.81	44.83
	5	57.79	59.33
	10	63.15	64.02
Times	1	44.73	46.00
	5	58.86	59.88
	10	63.56	64.07
News	1	41.86	43.90
	5	56.40	57.71
	10	61.41	62.26

Syntax gives an improvement in key saving of between 0.5 and 2% depending on the text and the number of predictions offered. The dictionaries for the texts contained in the region 700 to 1000 words, corresponding to the number of types (different words) in the text. The texts were put through PAL with a combined dictionary of 2600 words which therefore contained a number of extra words which were not in the particular text, the keysaving figures for these tests were approximately 3% lower, but with the same improvement due to syntax.

A further experiment was performed with the frequency information removed from the dictionary so that words for the prediction lists are chosen randomly according to the current prefix, but with no other criteria. The keysaving values with 5 predictions offered for the texts Times and Albans using their own and the 2600 word dictionaries are:

Text	Dictionary	Key saving %	
		No Syntax	Syntax
Albans	"own"	44.29	48.63
	2600	34.87	41.32
Times	"own"	45.47	50.80
	2600	39.52	45.81

In this case improvements in the range 4.3% to 6.4% are given by the inclusion of syntax.

DISCUSSION

In numerical terms syntax gave a lower increase in key saving than we had hoped. This discrepancy is probably due to the inability to predict with certainty the next word class in a sentence, there being a range of possibilities with various probabilities. The increase in key saving is also influenced by the fact that the key savings using frequency alone are high, with values around 50% (equivalent to 2 or 3 key pushes per word). In the situation where syntax alone was the factor in influencing choice of predictions a key saving increase of from 4.3% to 6.4% was recorded, indicating that the syntax mechanism is effective. It is less effective, however, than a system based on word usage or frequency statistics.

A syntax transition matrix could be constructed based on a greater number of preceding words, hence giving a higher order model which may be able to predict more accurately. This was not possible with the small text samples which we were able to tag, but larger corpora may give improved performance.

In the above experiments we have assumed that a complete dictionary exists containing all the words in the texts. In a working system this will not be the case as the dictionary may contain most of the words, but not all. It may be possible to infer an unknown words syntactic class using the transition probabilities of the words on either side of the unknown word. The suffix of a word may also be used to determine its syntactic class (12).

CONCLUSION

The inclusion of syntax in a predictive communication system does give some measurable gain in keysaving as well as an observed effect on the predictions. As well as improved keysaving there may be some benefit to a user in that they are guided towards a better use of English by the appearance of more appropriate predictions. There may also be a reduction in frustration as the predictor will offer fewer totally inappropriate predictions, for example words such as 'the', 'to', 'and', 'of' will not be predicted after a word such as 'the' has been entered.

The experiments have concentrated on the use of a small dictionary which contains all of the words in the text being entered. In normal use a small dictionary of 1000 words will contain only 75% of the words in a text (13). When a much larger dictionary is implemented in a portable PAL system, although there will be a greater chance of any given word being in the dictionary, more character selections may be necessary before that word is seen in a prediction list. Syntactic prediction may, therefore, give a greater relative benefit in this situation.

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A Communication Aid Which Models Conversational Patterns

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ABSTRACT

We have developed a prototype communication system that helps non-speakers to perform communication acts competently, rather than concentrating on improving the production efficiency for specific letters, words or phrases. The system, called CHAT, is based on patterns which are found in normal unconstrained dialogue. It contains information about the present conversational move, the next likely move, the person being addressed, and the mood of the interaction. The system can move automatically through a dialogue, or can offer the user a selection of conversational moves on the basis of single keystrokes. The increased communication speed which is thus offered can significantly improve both the flow of the conversation and the disabled person's control of the dialogue.

INTRODUCTION

The slow rate of communication of people using communication aids is a crucial problem. Although it may be impossible to achieve the 180-200 words per minute rate of fast natural conversation, but it is important to continue to explore ways to improve on present rates, which currently are an order of magnitude below that of unimpeded speech. We have approached this problem by realising that if one could produce a complete speech act with each keystroke, this would offer a significant increase in rate. Here we use the term 'speech act' in its widest sense: an utterance with a particular purpose. We began by undertaking a literature review of the field of conversation analysis, looking specifically for models of conversational patterns that we could use to build a system which produces speech acts appropriately. The system so far developed, called CHAT, uses a model of conversational interaction to predict what will be appropriate choices of conversational contribution to offer the user. CHAT is still in its early stages, and we plan to take its development further.

MODELLING CONVERSATION IN A MICROCOMPUTER

Casual conversation is one of a number of phenomena which until recently have been considered too formless for rigorous analysis. Conversation analysis is still developing as a separate field of study, nevertheless, it has produced a number of useful guidelines for building a simplified model of conversational interaction. While it is true that the possibilities for the next utterance in a given conversation are infinite, these are constrained by such factors as relevance, implicature, the conversational 'game' which is being played out by participants, and the goals that each has in mind [1,2,3].

A model for the overall contour of a conversation is shown in Figure 1. If we consider this as a pattern for a complete conversation, fragmentary encounters can be modelled by allowing the various elements to be optional.

We chose the opening and closing stages of a conversation as particularly suitable starting points for our work, since these are the most formulaic parts of an interaction [4]. We began with the stages: GREETINGS, RESPONSE TO GREETING, SMALLTALK, WRAP-UP REMARKS, and FAREWELLS. The MAIN SECTION of a conversation is normally some form of topic discussion, and this will be investigated in our future work.

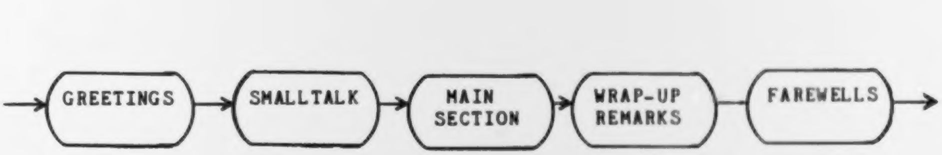

Figure 1 : Overall contour of a conversation

140

We decided that it was essential to incorporate one of the most distinctive features of spoken language in our system. This is the frequent occurence of conversational FILLERS in every sort of dialogue. These are vocalisations and phrases which we use, not because they have semantic content in themselves, but because they allow us to 'stall' for time while working out the next thing we want to say, or to hold the floor when we're not yet finished, or to keep the conversational rhythm going [5]. These gambits are necessary for all of us, but are of particular importance for an aided speaker. Filler remarks would significantly improve their participation and control of an interaction. It may be argued that such a facility might trivialise the interaction. We would say this is a misunderstanding of the nature of fillers, which fulfil a very important pragmatic task in an interaction, and are not meaningless 'noise'. A model of the use of FILLERS at any point in a conversation is given in Figure 2.

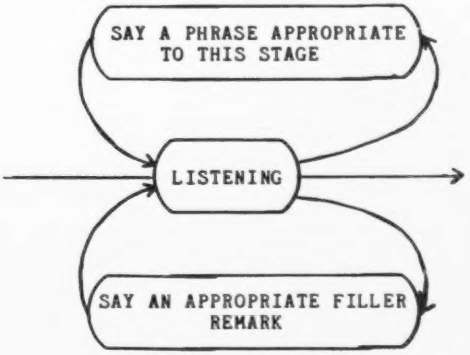
SAY A PHRASE APPROPRIATE TO THIS STAGE
LISTENING
SAY AN APPROPRIATE FILLER REMARK

Figure 2 : Possible utterances at any point in the conversation

CHAT -- A PROTOTYPE CONVERSATION AID

The CHAT system uses the conversation models shown in Figures 1 and 2 as a base structure. The further elements of the system that were developed reflect its ultimate purpose as a working conversation aid for a non-speaker whose input rate will be very slow. CHAT is designed to increase the communication rate by acting as automatically as possible, issuing appropriate contributions to a conversation with a single keystroke. Its name is an acronym of Conversation Helped by Automatic Talk. In its most effortless mode, CHAT will output speech on the repeated pressing of the same key, which might be labelled 'Say something appropriate here'. (More precise control of the output is always possible, but at the cost of increased key selections.)

The automatic production of conversational contributions is a possibility because of the predictability and repetitiveness of a large amount of natural conversation. An automatic system which was too obvious in its operation, and too dictatorial, however, would probably be unacceptable in the very human process of conversational interaction. In order to counter-balance this tendency, CHAT has an ability to simulate the natural variations and unpredictability of expression that occur in unimpeded utterances. It is also designed to take on the personal expressive style of the user.

In order to avoid repetitions of exactly the same phrase in any category, CHAT makes a random choice each time from a list of suitable alternatives for the current conversational move. (This is, in fact a constrained random choice, that does not produce exactly the same phrase until the other possibilities have all been used.) Thus, one person might be greeted by 'Hello there. How's it going?' whereas the next person might be offered 'Hi. How are you?'

The expression of personality and mood is an important purpose of conversation. CHAT allows the user to select a mood, and then all subsequent utterances will be given in that mood. So far we have experimented with POLITE, INFORMAL, HUMOROUS, and ANGRY moods. (We use POLITE as the default setting!) As an illustration, a FAREWELL offering in these four different moods might be :

POLITE:	Bye bye then. Enjoyed speaking with you.
INFORMAL:	Cheerio then. See you later.
HUMOROUS:	See ya later, pal.
ANGRY:	Goodbye, then. This has been a difficult meeting.

CHAT also contains a list of known people, whose names can be inserted automatically into the phrases as appropriate. A mood setting can be linked to any name, so that, for instance, close friends would always be spoken to in the informal mood. For easy changing and updating, the names and all of the phrases stored in the system are accessible through a simple editor. Our intention is for the user to put in phrases in these different moods to reflect their own personality and style. Thus, if an INFORMAL FAREWELL is requested, the system makes a random choice from a list of appropriate phrases, each of which reflects the user's style. This simulates what happens naturally, when we might have any number of ways of expressing the same thought, but a significant percentage of them will be qualitatively different from the way another person's expressions. The first set of phrases for CHAT were put in by a researcher with an American background. In operation, this reflects his personal style to such an extent that it provokes a humorous reaction from visitors when it is demonstrated by a British member of the team.

The output from CHAT can be sent to a VDU, or a speech synthesiser. We have piloted the system using volunteers to interact with a member of the research team, who only uses CHAT to speak. Two extracts from the recordings of these sessions are given below :

A : Hi, Mary, how are you?
B : I'm fine, thank you.
How are you?
A : Not bad, thanks, Mary. We're moving along as usual here.
B : That's good.
A : How have you been getting on?
B : Very well, thank you.

Time taken: 25 seconds Mood: Polite

A : Hi, Bill. How's it been going with you?
B : Pretty well, and yourself?
A : Just dandy thanks, Bill. What have you been up to recently?
B : The naughty things I couldn't tell you about.
A : Aye.

Time taken: 26 seconds Mood: Informal

We were very encouraged in general by the naturalness of the dialogues. It is interesting that, where CHAT did produce something inappropriate, the dialogue continued more or less intact. This is to expected from studies of the way natural conversations cope well with errors and omissions. If we produce transcripts with no clue as to who is the speaker using CHAT, as in the above examples, it normally takes a bit of study by an outside observer to decide which is the aided partner in the conversation.

What has given us most encouragement is the timing of these pilot runs. The examples above are typical. Because the aided speaker is producing an entire speech act for each keystroke, the rate is on the order of 70-80 words per minute (both speakers).

All our design work for CHAT has kept in view the desirability that the software should run on a wide variety of commercially available microcomputers. CHAT is therefore programmed in Pascal, a widely-used high level language.

CONCLUSIONS

A conversation aid based on modelling conversational patterns in the opening and closing stages has shown promise. We have begun work on including a facility for a range of feedback remarks to the other speaker. The next major part of our research will be to apply a similar approach to modelling the central part of a conversation: topic discussion.

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Predictive Programs: Writing Tools for Severely Physically Disabled Students

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ABSTRACT

This paper discusses the clinical applications of predictive linguistic programs, focussing specifically on one predictive program used for written communication. Case examples of two severely physically disabled adults who use a direct means of access are discussed. Clinical impressions and user recommendations are reported.

INTRODUCTION

Many physically disabled persons find adapted methods of access to the microcomputer too slow and tiring to serve as adequate writing tools in educational and vocational pursuits. A simple form of artificial intelligence referred to as predictive linguistics has been utilized by a number of developers to increase the speed and reduce the effort of writing by reducing the number of selections which need to be made to produce a given amount of text[1]. These developers have utilized the redundancy of the English language to create programs which predict or anticipate the words or message elements the individual may wish to enter[2]. An obvious advantage of predictive linguistics is that the user can enter whole words without the need to memorize a code or location.

One example of this approach, is a pre-boot program called "The Predictive Program", a modified version of "The Predictive Linguistic Program" developed at the University of Washington. This program runs on an Apple 2e utilizing the Adaptive Firmware Card and an extended 80 column card. The Predictive Program runs in conjunction with most word processors compatible with the Apple 2e and is toggled on and off by sending the ~ character. When the predictive feature is active, the user selects the first letter of the desired word. The Predictive Program, using information about the grammatical class of the preceding word(s), and about the statistical frequency of words within the English language, anticipates the completion of the word as well as presenting 6 or 10 alternate possibilities, numbered in sequence. The user can accept the anticipated completion by sending a space or can chose one of the alternate possibilities by entering the corresponding number. If none of the options is appropriate , the user chooses the next letter in the word. At this point a new set of predictions is presented to the user based on the additional input. The program presents lists of predictions following the first three letters of a word, if all these are rejected it will present possible suffixes. The program uses information about the frequency of occurrence of predicted words, as well as new words generated by the user, within the same session; this vocabulary is not saved for subsequent sessions.

The Predictive Program is displayed on the bottom of the screen: Text generated by the user appears in a text line near the bottom of the screen until a terminating punctuation or a return is sent (or until a small buffer is filled), when text is sent to the application program.

Within the past year, predictive programs have been prescribed for a number of severely physically disabled clients of the Augmentative Communication Service of the Hugh MacMillan Medical Centre in Toronto Canada. These clients range in age from 8 to 25, use a variety of access means (both direct and scanning), and have varying levels of linguistic competence. Two case examples are presented to illustrate the needs addressed and the clinical concerns which arose in prescribing a predictive program. Both individuals discussed use The Predictive Program to aid in written as opposed to face to face communication. Both individuals use a means of direct access.

CASE EXAMPLE 1

Benny is a 20 year old young man with cerebral palsy. He is unable to speak and augments his communication by using a communication display, with letters of the alphabet, words, phrases and Blissymbols. He also uses an Epson Hx-20 with Trine which is mounted on his wheelchair tray. Benny communicates in face to face interaction by pointing to items on his display, by spelling out messages, or by retrieving prestored message units using logical letter codes on his portable Epson computer, using his chin pointer. He is presently attending classes at grade 10 and 11 level in an integrated high school program.

Writing Needs

Benny's writing needs include personal correspondence with a number of close friends who live far from his rural home, school assignments, note taking, a journal, writing examinations, and creative expression (he is currently writing a fictional book). Benny has made the transition from writing with Blissymbols to writing using traditional orthography in the last 4 years. He has developed fair syntactical skills, but his spelling skills require further development.

Means of Writing

He is able to access a standard keyboard with guard using his chin pointer. He has an Apple 2e system at home and has occasional access to the a similar system at school. He is a proficient user of both Bank Street Writer and Magic Slate, two word processing programs for the Apple 2e.

Reasons for Prescription

The Predictive Program was prescribed for Benny to reduce the number of selections required to produce a given amount of text, thereby reducing the physical effort required to write. His resource teacher suggested that the predictive program would also reinforce word recognition and spelling skills.

Application

Benny has used the predictive program at home for approximately six months. Clinical observations indicate that although the number of selections required to produce a given amount of text has been reduced, the time taken per selection has increased. Rather than inputting letter by letter and occasionally gazing at the screen to insure that the correct letters have been entered, with the predictive linguistic program, Benny enters the first letter using his chin pointer, shifts his gaze to the screen, and visually scans the choices presented for the desired word. If the word is recognized, he decides upon the appropriate code for the word, shifts his gaze back to the keyboard to find the appropriate key to make his selection, enters this and shifts his gaze back to the screen to confirm his selection. Observations indicate a marked hesitation when Benny does not find the desired word in the list, possibly as a result of the need to shift cognitive fields from a recognition task to one of generating text. The net result appears to be a decrease in time taken to produce a given amount of text, but this decrease is not as dramatic as would be expected given the reduction in the number of selections required. An unexpected benefit was noted: Benny made fewer spelling errors and typographical errors using the predictive program than without the predictive program.

Recommendations

To decrease the physical effort of shifting his gaze from keyboard to screen, Benny requires a display within his visual field, when accessing the keyboard. Although easier to position, an LCD display with its small viewing angle would not be suitable for a chin pointer user such as Benny. Benny's computer system has been adapted to allow him to use his Epson Hx 20 as a remote keyboard for his Apple 2e. In this way the Apple 2e display and the remote keyboard can be more optimally placed.

If a method can be found to eliminate the need for number coding when accessing a predictive program through a direct access means this may be more beneficial for Benny, as the cognitive effort required to select a predicted word would be reduced.

Benny may benefit from personalizing of the predictive dictionary through the addition of contextual vocabulary files which can be selected when writing about a given topic. However, a predictive system which adds new vocabulary generated by the user to it's dictionary would not be suitable for Benny as any mispelled words would then be included.

Despite the concerns discussed above, Benny wishes to continue to use the predictive program. It may be that as Benny's competency and fluency in writing improve he will need to devote less cognitive energy to the formulation and spelling of text, freeing him to attend more directly to the benefits of The Predictive Program. It is anticipated that the more optimal arrangement of the keyboard and screen will reduce the physical effort of shifting gaze required in the past.

CASE EXAMPLE 2

Sylvia is a 25 year old woman with cerebral palsy. She is presently participating in upgrading courses in preparation for enrollment in a university creative writing course. Speech is her primary means of face to face communication.

Writing Needs

Sylvia's writing needs are numerous, including personal correspondence, creative expression, course assignments, and note taking. She composes poetry, short stories and articles for publication in periodicals and journals on a large range of topics. Sylvia's primary concern is to have access to a reasonably fast mode of writing when participating in university courses in the near future.

Means of Writing

Sylvia has an Apple 2e professional system at her apartment. She has used both Applewriter and Appleworks for word processing. She uses large uncoordinated movements of her right arm to access an expanded membrane keyboard with a guard. Although this is the fastest means of access for Sylvia, it is a slow, laborious process. She has access to word /phrase entry through the customized set up of her membrane keyboard (i.e., a number of keys are redefined to send commonly used whole words and phrases to the computer), as well as through the limited macro feature of Applewriter. A tutor assists her in setting up the computer system.

Reason for Prescription

The major goal in prescribing The Predictive Program for Sylvia was to increase her writing speed and decrease the physical effort required to write.

Application

Sylvia has used The Predictive Program for approximately 9 months. She is enthusiastic about the benefits of the predictive program. She has developed a number of personal strategies to achieve the most effective use of the predictive program. When initially composing or generating ideas about a story or poem, she turns the predictive program off so that she is not distracted by it and enters an outline of cue words and personal codes. She turns the Predictive Program back on, when she begins to draft her full text. At this point, she uses the predictive program primarily to enter words which are more redundant in the English language (e.g., verbs, functors, adverbs), frequently ignoring the program when entering specific content words. She also prefers using an habituated code or abbreviation for a small number of long, context-specific words or terms, using the search and replace feature of the word processor to expand the abbreviation. She uses the full features of the predictive program when composing routine correspondence, which is less cognitively demanding.

Since Sylvia makes occasional, unintentional double hits and incorrect hits, she habitually looks at the screen to monitor her selections. The predictive program does not appear to require her to significantly increase the number of times she shifts her gaze.

User Recommendations

Sylvia is pleased with the predictive program, she feels it makes the process of getting thoughts to paper less laborious. She has a number of suggestions for improvement to the specific predictive program used.

1) The Predictive Program uses a large amount of the extended memory of the Apple 2e, leaving little room for text files on word processors also using the extended memory. She would like a predictive program which is completely transparent to the word processing program.

2) She would like a program which is present whenever the computer is turned on; she feels the present set up procedure takes too long (prebooting the predictive program).

3) She finds the text buffer of the predictive program disconcerting as a certian amount of text scrolls off the text line at the bottom of the screen but does not appear in the application program until the next string of text is sent.

4) She would like a program which has user modifiable, context specific vocabulary files which can be easily selected.

5) She suggests a program which does not require entering a number code to select the desired word, she suggests a device where the predictions would appear on designated keys on her keyboard, the labels of these keys being transient.

SUMMARY

In prescribing a predictive program the clinician needs to consider not only the decrease in the number of selections required to produce a given amount of text, but also the time and effort needed to make each selection. The clinician should consider the following questions:

1) Does the process of accepting or rejecting a selection demand significantly increased cognitive effort of the client?

2) What is the effect of the repeated visual reorientation required to visually scan through contantly changing selection sets?

and,

3) What effect does the need to repeatedly shift gaze (when using a direct method of access) have on the physical effort required to make a selection?

In conclusion, predictive programs are potentially useful tools for written communication for severely physically disabled individuals. Further technical development would enhance the usefulness of predictive programs. This technical development must be coupled with clinical application and research to learn more about the cognitive/linguistic demands of such programs.

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LINGUISTIC EFFICIENT COMMUNICATION SYSTEMS; CONSIDERATION OF FEEDBACK PRINCIPLES

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ABSTRACT:

Redundancy in language has a function in error detection and recovery. Imprecise expressions, choice of wrong words, incorrect pronunciation, errors in spelling of written text and errors in syntax can cause a misinterpretation of the message. However, due to redundancy in language, a listener is often able te detect and recover those errors. This is a rather unique human ability. This error correction ability might be reduced when a communication system is used with a less redundant coding principle. Prediction, coding and abbreviation systems are based on linguistic redundancy to optimize its use in communication.
Thus, in these systems, an error correction procedure will be much more important than in "full text" communication systems.
This paper will deal with the discussion of fundamental background of feedback and error correction and will discuss some feedback principles for error correction.

PROBLEM DEFINITION:

Modern communication systems which make use of computer technology are relying on redundancy in written text. This redundancy is used in present systems to predict text (characters or words) or to optimize the layout of keyboards and coding and abbreviation systems. Linguistic knowledge can also be used in automatic decoding systems. This is an interesting approach which is using a small number of keys, for example a telephone keypad, with each key representing a number of different characters. Activation of one key can than have several possibilities of characters, but due to redundancy in text, a computer can decode automatically the correct character (Minneman, 1986; Foulds et al, 1987).
A serious problem which has to be solved before successful field application of this automatic decoding, and also the prediction, technique can be expected, is the correction of errors. These systems are using statistical knowledge, and therefore errors will occur: in automatic decoding the errors in decoding a 30-character set on a 10-key keyboard is less than 10 percent. In predictive systems, the error percentage is strongly dependent on the span of prediction (letters, words or even sentence parts) and on the knowledge base in the computer (reliability of tables of frequency counts of character strings, completeness of stored vocabularies, present topics in the text database of the statistical tables, etc.). A demonstration of what a unsufficient error correction procedure (feedback) can do to speed of text generation is shown in literature (Bernstein, 1986). Error correction can be so time consuming that a 20 percent keystroke saving by prediction can still mean a slower generation of full text.

One might agree that fast entry systems will mainly be used in direct person to person communication and therefore can be tolerant to errors. This will certainly not be true if synthetic speech units are connected: misspelled words will cause completely unintelligible pronunciations. Misspellings on paper or on a visual display unit might be less misleading for the "listener", but certainly will decrease the fluency of communication.

THE FEEDBACK SITUATION:

An approach which we will take in studying error correction is beginning with looking at the viewpoint of the person who sends information ("speaker"). If communication takes place without the help of a device or intermediate aid, the speaker spells or speaks words, characters or signs; the listener receives piece by piece the information and acknowledges this by an eyeblink or just by facial expression. If not acknowledged, the speaker repeats or modifies the message (immediate feedback). Using a communication aid, the speaker constructs his message via the technical system and, in direct communication, receives feedback about small portions of a message from the technical system and functional feedback from the listener.
For an optimal system design it is necessary to study the interaction with the communication system and the listener in detail. The next paragraphs discuss therefore this situation in detail.

REGULATING AND CONTROLLING COMMUNICATION:

To study efficient input systems, it is necessary to examine some bare essentials of communicative interaction between two persons with respect to the following:
- Conversation strategies.
- Controlling the conversation.
- Speaker- and listener contributions.

Some of these organizing and regulating mechanisms can be of use for implementation on efficient input devices of augmentative communication systems.
In the latter case the augmentative system has to simulate "interpretative, acknowledging" roles of the "listener".
When two persons are involved in a conversation, one of the persons, wants to convey an idea (an intention), formulates it (as prepared in mind), and expresses it. The other person receives the message and will plan a reaction or acknowledgement and expresses it in a similar way. A sequence of speaker-listener turn exchanges occurs along with changes of topics until the interaction ends.
During interaction, there is a mutual participation in which each person's role is clearly defined. The conversation usually flows, smoothly from beginning to the end in a specific

topic oriented order and a mutual accepted rate. While involved in conversational acts "speakers" and "listeners" frequently exchange information about (non) acceptance of topic/theme, conversational turns, output quality, attention-preservers and so on... Information which is of use in building up the communication process. Especially "feedback strategies" or "back channel communication" indicate regulation and control of the conversational interaction. Besides its regulatory role, feedback appears to be very important in providing monitoring of the quality of communication (e.g. intelligibility of speech output).

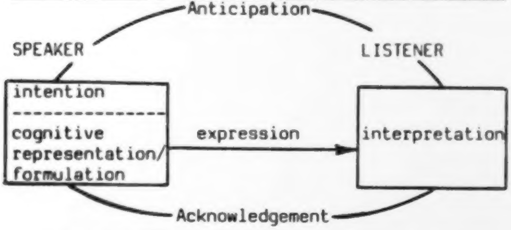

Fig. 1 Dyadic situation

Apart from some general prerequisites for communicative interaction, the above process differs extremely for nonvocal persons using an augmentative communication system. Most striking is the use of qualitative different and longer feedback strategies of vocal partners, in trying to assist or extend their nonspeaking partners during message transmission. These long back channels function as acknowledgements of the nonspeakers' contributions.

Most of the time and effort is spent on "cognitive respresentation and formulation". The physical expression of the message is the immediate result of the intention. The listener tries to recognize and understand the message and will otherwise ask to reformulate the message. Each speaker is responsible for a good understandable formulation and expression of his intentions.

In case of a nonvocal person, using an augmentative communication system, who wants to communicate, the process described above is much more difficult. There are more steps involved between "intention" and "expression". These steps involve necessary actions to deal with a communication system: additional sensory and motor activity is needed. Besides that, there are some other important differences:

- Listener participation

  In normal vocal interaction the listener basically listens and waits for his/hers turn. In interaction with a nonvocal person, the listener has often an active role in the generation of the message. In this case, the traditional turn-taking protocol in conversation is disrupted which affects speed and ease of communication.

- System interference

  A nonvocal "speaker" has to select, sequentially, message elements with his system. The speaker and listener both need to keep the whole message in mind while it is in an assembling phase. The "speaker" also needs to deal with the possible asserting or correcting interference of the listener. The "speaker" must choose either to ignore the interruption or stop, acknowledge its accuracy, and proceed with the next appropriate step. Or, much more complex is when the listener changes topics suddenly which leaves the "speaker" in the middle of expressing an not anymore relevant and anticipated thought.

The above means that the "technical" part of a communication process can be much more complicated and exhaustive; it also involves deviant and not well defined speaker-listener roles.

A typical occurence in dyadic interaction between speaking and nonspeaking partners is the lack or absence of conventional feedback, signaled by the nonspeaking persons. So, the speaker often assumes that the "nonspeaker" either does not understand or is not interested. Subsequently it occurs that he simplifies his speech or even terminates the conversation (Blau, 1986).

Feedback plays an important role for the speaker in monitoring and planning the message-construction and -transmission. The listener's responsive behavior indicates the effect of a message. The wide variety of feedback procedures in normal interaction is reduced in vocal-nonvocal interaction to the primary purpose of evaluating the listeners' interpretations of the nonspeakers' utterances/messages.

Nonspeakers produce few attentional or acknowledgement signals. Furthermore, the information flow is retarded by the necessary use of extraneous specifications, clarification requests, questions and repetitions.

Feedback in interaction with augmented nonspeakers predominantly is provided by the "speaking" partners (even in listener roles). The "speaking" partner gets a regulatory, controlling and very active role in extensively using back channeling.

Nonspeakers predominantly spell out entire messages with their alphabet/word or symbol systems.

The amount of turnexchanges necessary for the construction of a message is characterized by many feedback utterances of the "speaking" partner. Often this leads to a frustrating mismatch between the communication partners.

WHAT CAN BE LEARNED FROM INTERACTION STUDIES?

As indicated above the communication process heavily relies on regulatory and control procedures; especially characterized by feedback or back channel processes.

The lack of convential back channeling may play a dominant role in creating mismatches between speaking and nonspeaking communication partners. So, it could be of use to operationalize feedback strategies on efficient input mechanisms, which use prediction, abbreviation and coding. Techniques in which feedback plays a crucial role. In that case the following issues are of relevance:

1. Lexical access and vocabulary size.
2. Linguistic elements.
3. Linguistic code transformation.
4. Dealing with concepts.
5. Acknowledgement (feedback/monitoring).
6. Social aspects.

Ad 1 Lexical access and vocabulary size
The main question here is what kind and size of a vocabulary is needed by a nonvocal person? This will depend on his level of education, needs and situation. Furthermore, the access to a lexical database is a major concern. How should it be organized and what control structure is efficient?

Ad 2 Linguistic elements
What will be the most adequate and efficient representation of vocabulary elements for a specific user (words, graphemes, codes, symbols)?

Ad 3 Linguistic code transformation
Speaker and listener have to use the same language (linguistic code) in order to understand each other.
Most of the known "prediction" and "abbreviation" systems use the alphabet. But an intermediate language can be of use, when the nonvocal person prefers to communicate in another language form than his communication partner. The use and function of a "translation system" can be of special relevance when written or spoken output of messages is wanted.

Ad 4 Dealing with concepts
Most prediction systems are based on language statistics (p.e. frequency tables of linguistic elements). Classification of words as semantic clusters, sharing the same "concept" will be a future problem, when input systems will include syntax and semantics in the procedures. In an earlier stage it can be expected that grouping of word frequency lists with the same meaning relations enhance the efficiency.

Ad 5 Acknowledgement
In a normal communication we "unconsciously" monitor our expressions in order to compare the message with our intended meaning. When using a prediction or abbreviation code, acknowledging the correctness of a message is important, but demands a higher level of consciousness. Most prediction or abbreviation techniques use the redundancy in language. Thus, in case of a less redundant coding of a message, an error might have more effect and an acknowledgement takes more effort and time.
Possible techniques:
o Word- and sentence-completion.
o Error indentification (p.e. correction suggestions on spelling errors).

Ad 6 Social aspects
The selection of optimal vocabulary (-size), concepts, linguistic code is dependent on the environment and the need for communication.
The acceptance of an augmentative device is also dependent on the adequacy and efficiency of the system.
Training is needed for many systems, but it is not known to what extend training is allowable.

The issues rely on the availability of adequate and representative language corpora. In order to decide on representiveness it is necessary to define the needs from the viewpoint of actual use.

Information from child and adult language interaction studies could give this information. At this time it is not known what the optimal corpus for linguistic analysis would be as a basis for implementation in a prediction or abbreviation system.

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DESIGNING ENHANCEMENTS FOR AND PROVIDING TECHNICAL FEEDBACK TO MANUFACTURERS OF AUGMENTATIVE COMMUNICATION EQUIPMENT

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ABSTRACT

The Assistive Device Center, (ADC), is funded by P.L. 94-142 monies which are allocated through the Pennsylvania Department of Education, Bureau of Special Education. Technically advanced, commercially available augmentative communication equipment is provided to students on a long-term loan basis. During the 1985-1986 school year, 160 augmentative aid systems were distributed throughout the State of Pennsylvania. During 1986-1987, 153 additional systems will be distributed.

The ADC rehabilitation engineer has a unique opportunity to provide feedback to manufacturers and influence improvements on equipment. Recipients are followed-up to insure that the equipment is being effectively used. The ADC staff is keenly aware of any difficulty the consumers have putting the equipment to work. Documentation, software, electrical hardware and mounting kits with design flaws translate into complaints and frequent requests for assistance.

This paper describes several product enhancements that are being developed at the request of clinicians and consumers. Technology transfer to the manufacturer is also explored.

INTRODUCTION

Microprocessor technology has had major impact on the field of augumentative communication. There are now at least half a dozen commercially manufactured computer based products designed to assist disabled children or adults with verbal and written communication. These devices are light-weight, portable, battery powered and highly programmable by the end user. Both the method of input selection and the choice of store phrases can be highly customized by the therapist, teacher or parent working with the client. While these devices are expensive, the cost is similiar to that of a quality electric wheelchair. Five years ago, this technology was available only in research settings. Now, thousands of these devices are in use throughout the United States and overseas.

The sudden influx of computerized communication aids has created an additional learning task for teachers and speech and occupational therapists who must now add computer programming to their list of skills. The very benefit of having this technology available has presented a new challenge to manufacturers and service delivery rehabilitation professionals providing technical familiarization and training to a large body of geographically separated persons.

Unlike the regular computer industry, manufacturers of microcomputer based augmentative communication aids typically produce less than one hundred devices a month. The cost of a quality users' manual plus technical consultation services can easily exceed the development cost of the hardware it supports. In addition, engineers who have the skills to design the equipment do not necessarily have the skills to provide non-technical instruction.

Because clinicians implementing augumentative communication equipment are spread out geographically, they must often learn through self-instruction. It often falls on the shoulders of the distribution agency to provide necessary supplemental training. The Pennsylvania Special Education Assistive Device Center ,(ADC), invests much of its staff time in training teachers and therapists. A toll-free phone line (technical hotline) is maintained for loan recipients to use. Two ADC staff, the rehabilitation engineer and a technology specialist, spend approximately half their day providing technical instruction and trouble shooting.

BACKGROUND

Since its beginning in 1985, the ADC has created a multitude of training and technical services in the use of augmentative communication aids for school personnel. In addition to the toll-free hotline, instructional video tapes, fact sheets, regional seminars and a quarterly newsletter are provided

In September 1986, the rehabilitation engineer recommended that the ADC commit a portion of his time to developing enhancements to existing augmentative devices and passing on these enhancements to manufacturers for distribution.

Since the ADC services are supported by public funds, a conflict of interest would be created if the ADC accepted any development money from a manufacturer who was also a vendor of equipment. It was decided that any collaboration efforts with a manufacturer could not involve the exchange of funds. It was also decided that the rehabilitation engineer's time would only be used for device modification that would immediately and directly benefit the recipients of long term loan equipment.

Several ideas, requested by clinicians and presently under development at the ADC, include:

1. Photo-illustrated tutorials to coach teachers through setup procedures of augmentative equipment.

2. Methods for using existing wheelchair mounting kits to hold communication aids on pediatric size wheelchairs.

3. Methods to interface large, two-sided liquid crystal displays to existing commercial communication aids.

The principle project described in this article arose through the technical hotline Records of phone calls are reviewed monthly with the goal of providing better solutions to problems that come up frequently. Approximately 50% of all phone calls received request assistance in programming the Light Talker™ and Touch Talker™ communication aids manufactered by the Prentke Romich Company.

A collaborative relationship was developed between Prentke Romich Company and the ADC. Before describing the project, some general information on the Light Talker/Touch Talker communication aids is provided.

FEATURES OF THE LIGHT TALKER AND TOUCH TALKER COMMUNICATION AIDS.

The Light Talker/Touch Talker are microprocessor driven devices which provide a text-to-speech artificial voice through a sophisticated software operating system, called MINSPEAK™. MINSPEAK permits the end user to totally personalize both the expressive vocabulary and the sequence and location of keystrokes that will invoke each phrase. MINSPEAK contain 56 functions stored in Read-Only-Memory (ROM) that allow the end user to totally personalize the layout of the 128 key positions on the front panel. Minspeak software uses the technique of semantic compaction. It is a powerful concept that allows even non-readers and non-spellers to invoke useful sentences by associating the sentences with picture labeled selection sites.

The Light and Touch Talkers use the same operating system, but the Light Talker provides the additional feature of accepting input by an optical headpointer or through alternative switches instead of by direct keystrokes. Since the Touch Talker has mechanical keys and the Light Talker is optically selected, the author, when referring to a location on the front panel of either device will use the term "selection site".

Other augmentative aids such as the Epson Eval-Pack™ or Zygo Notebook™ use a mass-produced, portable microcomputer as the hardware base. With these machines, the user receives a familiar typewriter style keyboard. The PRC Light Talker and Touch Talkers have a grid style entry panel. The 128 selection sites are arranged in 8 rows and 16 columns.

The selection sites are totally user assignable. The user can program a selection site to:

1. Enter a single alpha-numeric character in the manner of a conventional keyboard.

2. Invoke a programming function, i.e. turn the voice on or off.

3. Be a picture/symbol key that is used to retrieve a stored phrase.

Often, the same key will perform several of these tasks depending on which mode the machine is in.

The front panel selection sites are identified by flexible white vinyl sheets called overlays. Either one of several factory overlays can be used or a totally customized overlay can be created by beginning with a blank overlay and attaching pictures, symbols and letters of the user's' own choosing. Except for the factory overlays, which are defined in ROM, each selection site must be explicitly programmed with its control function, icon title or character.

In addition, both the Light Talker and Touch Talker have the ability to group together selection sites on their front panels into larger targets which then behave as one large selection site. The front panel can be be set up as 128 selection sites each one of which is 3/4 of an inch square; 32 selection sites each one of which is 1 1/2 inches square; or 8 selection sites each of which is 3 inches square.

The concept of a software defined keyboard with variable size selection sites can be difficult to learn. The Light/Touch Talker has no way of "knowing" what labels have been attached over its selection sites. It maintains an internal memory map of its front panel.

Since the Light Talker and Touch Talker can hold over 30,000 characters of vocabulary, a battery failure could require considerable reprogramming. Prentke Romich markets the Memory Transfer Interface, a special software package for the Apple computer, which will transfer a copy of the Light Talker or Touch Talker's memory to an Apple floppy disk.

PROJECT METHOD

In early December, 1986, the author wrote to Barry Romich, the president of Prentke Romich Company, and proposed to develop some modifications to the Light Talker/Touch Talker series of communication aids. The author visited the Prentke Romich factory in Ohio for two days in late December to discuss details, interview Prentke staff engineers and gather technical information.

Based on inquiries from the technical hotline, users are having three major difficulties programming the Light/Touch Talkers:

1. Unpredictable results from the Memory Transfer Interface, (MTI-2),. Many users described situations where they had attemped to restore memory from an Apple computer to a Light/Touch Talker and ended up with a completely blank memory. The ADC rehabilitation engineer had investigated the software and found several ambiguous statements in the screen instructions.

2. Difficulty keeping track of front panel selection site assignments. Frustration occurs when the command functions and symbols marked on the vinyl overlays, no longer coinside with the Talker's internal memory map. Users tend to have a fundamental faith in keyboard labels. All their prior experiences with typewriters and terminals has taught them to trust key tops - if the key top is marked with "A" they expect an "A" on the screen whenever they strike it. When keys no longer do as expected, they feel betrayed by the machine. While the Light/Touch Talkers are capable of telling the user the status of any selection site, the information is conveyed through a small 40 character liquid crystal display. Each selection site must be individually interrogated.

3. Vocabulary can be hard to track. Although Minspeak provides a function called "REVIEW VOCAB" which sends a lists of stored sentences to either the LCD display or an attached printer, the user has to provide the "Theme", (first icon or keystroke of the retrieval sequence), before "REVIEW VOCAB" will work. Since the the L/T Talkers have 128 possible themes, it could be necessary to invoke "REVIEW VOCAB" 128 times to be sure of printing out all possible vocabulary.

Various methods of improving user friendliness of these aids were discussed with the Prentke Romich Company staff..

One method would be to make hardware changes to the existing Light Talkers and Touch Talkers. The task of designing and retrofitting new ROM chips would require the ADC rehabilitation engineer to learn most of the operating system (written in 1802 assembly language). The engineer's time budget would not permit this level of investigation.

An alternative proposed by the author was to write a software utility that would correct the inadequacies of the MTI-2 and additionally provide the users with a chance to inspect the contents of their back-up files.

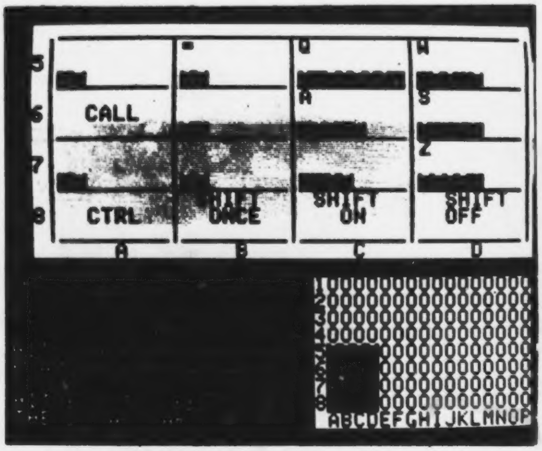

Figure 1: A photograph of an Apple computer monitor after running the **Examine** program. This program decodes Touch Talker and Light Talker memory files and displays the front panel selection site assignments.

QUESTION EAR
QUESTION
QUESTION
QUESTION ELEPHANT
JUMP

Figure 2: A photograph of an Apple computer monitor as the **Examine** program decodes and displays the vocabulary from a Light/Touch Talker file. This vocabulary can also be sent to a printer.

RESULTS

The Enhanced MTI-2 was written between January and March of 1987 by the ADC rehabilitation engineer. The new software translates the binary backup files into the front panel layout and provides complete vocabulary listings.

Figure 1 shows an Apple computer monitor after running the **Examine** program. There is only room on the monitor to display one eighth, (sixteen selection sites), at a time. A global map is provided in the lower right hand corner of the screen to show the user where he/she is located on the front panel.

Character assignments are displayed in the upper left-hand corner of a cell using a black character on white background. Command functions are displayed in all capital letters across the center of a cell. If an icon label has been assigned, it is displayed across the bottom of a cell using white letters on a black background. Cells which have not been assigned commands or icon labels default to their grid coordinates. Hitting the spacebar shifts the global map marker over to the next group of sixteen cells. The panel display and coordinates are redrawn to reflect the new locations.

Figure 2 shows the beginning of a vocabulary display. The icons or grid corrdinates that represent the symbol sequence are displayed first in inverse video followed by the stored message. If two different versions of the message are used, one to be displayed and one to be spoken by the speech synthesizer, each version is preceeded by the word "TEXT:" or "SPEECH:" Stored functions are marked by the words "COMMAND FUNCTION". Once started, the entire vocabulary will scroll up the screen. The vocabulary can also be sent to a Apple Imagewriter™ printer.

CURRENT STATUS AND FUTURE PLANS

The Enhanced MTI-2 software has been completed. Copies of this software are being released to therapists and teachers who are doing extensive vocabulary development. Copies are also being supplied to Prentke Romich Company.

If sufficient demand exists, the development of a full featured authoring system will be considered. This authoring system would be implemented on an Apple IIe or Apple IIgs and include the use of an Echo +™ Speech Synthesizer Card to try out the pronounciation of messages being created. Besides allowing vocabulary to be entered with a text editor, special editing features could be provided in an Apple environment that presently does not exist in Minspeak.

Special editing features could include:

1. The ability to rearrange the icons and commands on the front panel without having to reprogram all the messages. The revised overlays could be printed using a color, dot matrix printer.

2. The ability to merge two different vocabularies into one communication aid. This feature would encourage third party authoring of vocabularies. A teacher could obtain a vocabulary written by a professional speech therapist and still include the student's personal set of words and phrases.

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CLINICAL APPLICATION OF AN AUDITORY SCANNING SOFTWARE PROGRAM WITH SEVERELY DISABLED, NONSPEAKING INDIVIDUALS

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ABSTRACT

Many nonspeaking, severely disabled individuals are confronted with their inability to effectively utilize any of the commercially available augmentative communication devices and software due to confounding visual impairments associated with their neurological conditions. This paper describes an auditory stimulus scanning software program and its clinical application with some nonspeaking quadriplegic individuals seen in the Rehabilitation Institute of Chicago's Alan J. Brown Center for Augmentative Communication and Environmental Control.

INTRODUCTION

Nonspeaking, severe physically disabled individuals who possess visual acuity and/or perceptual deficits have been generally restricted in the number of augmentative communication systems available for their use. As a result of their visual impairments, these individuals are often forced to communicate via an augmentative communication system that is not fully compatible with their linguistic capabilities and communicative needs. Within the past 3-4 years, this population's needs have begun to be addressed with the emergence of some specially designed commercially-available software programs, such as the Say-It (1), the Audio Scan (2), and the Talking Scanner (3). Other augmentative communication specialists, Beukelman, et. al. (4), Lee, et. al. (5), and Fried-Oken, et. al. (6), have documented their results concerning the clinical application of custom-designed auditory scanning software programs for some of their nonverbal clients with severe physical disabilities and visual impairments.

Because the majority of the commercially available software programs, previously stated, did not provide the user with independence in producing novel utterances via the selection of individual alphanumeric characters, system selection for these types of clients seen in the Brown Center was quite challenging. As a result, researchers in the center set out to develop an auditory-based scanning software program which would facilitate the establishment of an augmentative communication system which would allow them the capability of producing novel messages of various lengths as well as recalling pre-stored vocabulary or messages.

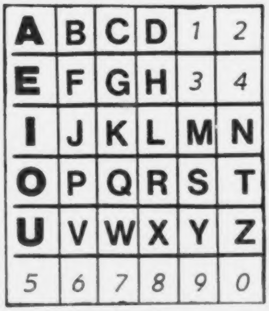
SOFTWARE DESCRIPTION

The RIC Easy Talker is a single switch-controlled row-column scanning software program which has as its basis a main matrix display of large, bold alphanumeric characters and various control function symbols (See Figure 1). Two letter arrangements are available: 1) traditional alphabetical sequence, and 2) frequency of letter usage. The alphabetical arrangement version is based on a user-friendly communication board for nonverbal individuals with severe physical disabilities previously developed at the Rehabilitation Institute of Chicago (7) (See Figure 2). The program's other unique features are as follows:

1. An auditory and visual scanning alphanumeric main matrix display and letter files of stored vocabulary/message items.
2. User-controlled:
   ____Word/phrase/sentence memory storage and retrieval capabilities.
   ____Quick retrieval of "emergency or frequently used" messages.
   ____Organization/ordering of vocabulary/messages within letter files.
3. User-adjustable speed of the scanning "box" cursor.
4. Editing capabilities for both spoken and written communication.
5. Speech output and printer options.
6. Utility programs for keyboard entry of vocabulary/messages into the memory and/or an exception table for phonetically-spelled words.
7. Simple tone generation ("alarm") for attention-getting purposes.
8. Matrix display letter and numbers selected and text generated by the user are in large, bold 5/8" characters, using a 13" monitor screen (See Figure 3).

Figure 1

Easy Talker runs on an Apple II+, IIe or IIc computer and uses a full 64K bytes of RAM (therefore requiring a language card if the II+ is used). The program is written in Applesoft Basic and 6502 Assembly Language and runs under Apple DOS version 3.3. The menus and the message line are comprised of large, enhanced, easy to read characters formed using Apple's high resolution graphics. The user operates the program with a simple momentary-closure switch that connects via the computer's paddle (I/O) connector. The entire program is supplied on a single distribution diskette. This diskette also holds the phrases and messages which the user builds, stores and retrieves. There is enough storage on the diskette to hold approximately 100,000 characters, which translates to more than 3,333 possible stored messages. System requirements include the following peripherals (in addition to the computer): computer monitor or T.V., one disk drive, either the Votrax "Personal Speech System" or "Type 'n Talk" with interface card, page printer with interface card and switch interface.



A	B	C	D	1	2
E	F	G	H	3	4
I	J	K	L	M	N
O	P	Q	R	S	T
U	V	W	X	Y	Z
5	6	7	8	9	0

Figure 2

CLINICAL APPLICATION

This auditory scanning software program thus far has been found to be beneficial for nonspeaking, severely disabled individuals who have sustained brain stem infarction or brain trauma. Prerequisites for independent utilization include the following: 1) consistent single switch interface control, 2) functional memory and auditory comprehension skills, 3) adequate spelling and phrase/sentence formulation skills, if utilized without the speech synthesizer, and 4) good spelling and message formulation skills, if utilized with the speech synthesizer.

CASE 1

The first user of the Easy Talker was a 33 year old male who sustained brain stem ischemia in 1983 with resultant locked-in syndrome and quadriplegia. Double vision reported by the patient interfered with his consistent and reliable perception of small print. During his rehabilitation, he progressed through a variety of augmentative communication systems: head nod or upward eye gaze for YES and headshake for NO, a listener-controlled alphabet spelling system/ board (7), and an Apple IIe computer-based communication system with the Handicapped Typewriter column-row scanning software program (developed and produced by Rocky Mountain Software). Control of the latter system was via a thumb-activated micro-switch built into a hand splint. This switch interface system was jointly developed by the occupational therapist and rehabilitation engineer. One disadvantage of the computer-based system noted upon follow-up was the need for his listeners to constantly remain in view of the monitor's screen to read his messages. Because he experienced recurrent inflammation of his eyes, his consistently accurate use of the Handicapped Typewriter program was compromised. In addition to these problems, the menus of this program were displayed in the 40-column character size generally seen in computer-generated text. Thus, it was difficult for the individual to perceive the word/phrase items in the letter files of the memory and to retrieve them with consistent reliability.

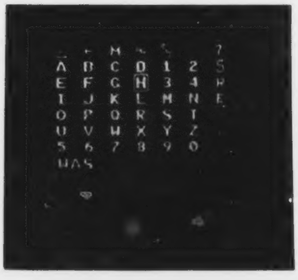


Figure 3

Following the Easy Talker's development, his evaluation with it yielded positive results. The only disadvantage that remained related to his reduced spelling ability, which occasionally interfered with the spoken output of his messages. His family and other caregivers were instructed to assist him in his spelling of his stored vocabulary/messages when necessary to insure their clarity upon being spoken by the Votrax Personal Speech System synthesizer.

Currently, the client has been utilizing this system for several months and has reported satisfaction with it. Family members and caregivers have been positive in their comments regarding his use of it, stating that his accuracy and speed in message conveyance has improved, and the addition of the speech synthesizer has eliminated their need to always view the screen for his message and increased his potential for communicating on the phone.

CASE 2

This 34 year old male sustained cranio-cerebral trauma in a motor vehicle accident in 1981 with resultant quadriparesis and severe brain stem injury. During the course of his recovery, as his awareness and responsiveness to his environment increased, he gradually progressed from inconsistent eyeblinks to indicate YES and NO to consistent eye gazes to a 4-8 word ETRAN display, then to a listener-controlled alphabet spelling system (7). With improvements in motoric control, he began to utilize a simple auditory scanning software program with a Radio Shack Color Computer, speech synthesizer and page printer. Control of this computer-based communication system was via an infrared eyebrow wrinkle switch. This system provided him with the means to produce some single word responses to convey his basic needs and feelings. Reportedly, after discharge from this facility, his functional use of it was inconsistent for various reasons, and he relied upon the listener-controlled alphabet spelling system with which he produced words, phrases and sentences.

In 1986, he was re-evaluated in our center with the Epson HX-20 computer-based PACA (portable anticipatory communication aid), the Light Talker with Express software and the Apple IIe with Easy Talker software program. Control of all 3 systems was assessed using the P-switch by the center's occupational therapist. Results of trials with each of these row-column scanning communication systems revealed that the client was significantly more accurate in letter/ word/ message selection using the Easy Talker program primarily because of the large, bold characters and auditory scanning feature. Several reasons for his heightened performance were plausible. First, he had been consistently using the listener controlled alphabet spelling system (see Figure 2) auditorily for 3 years with his communicative partners, and was thoroughly familiar with the letter arrangement which served as the basis for the main matrix display of the Easy Talker. Secondly, although reading comprehension was functional for newspaper articles, he displayed significant latencies in reading due to reduced visual tracking skills. Thirdly, the client himself indicated a preference for the monitor screen with large, enhanced characters and auditory scanning presentation of characters as opposed to the smaller LCD screens on the PACA and the Light Talker, since it facilitated error awareness and self-correction during message preparation.

Currently, the client is utilizing the Easy Talker program with an Apple IIe computer, Votrax speech synthesizer, and P-switch control interface to communicate with his family, caregivers and therapists at his residential facility. Further upgrading to a portable version of his augmentative communication system is being explored.

CASE 3

This 15 year old female with a diagnosis of locked-in syndrome secondary to trauma with resultant quadriplegia, visual acuity and/or perceptual deficits was initially evaluated in 1982. Initially, her only means of communication was via an upward eye gaze for YES and downward eyegaze for NO. Since 1982, she has utilized the listener-controlled alphabet spelling system (7), and the Apple IIe computer with the Handicapped Typewriter software program and page printer with varying degrees of consistency and success. Control of the computer-based communication system has been via a thumb-controlled microswitch built into a hand splint developed by the occupational therapist and rehabilitation engineer.

Due to the persistence of her visual impairments and involuntary head movements, she has tended to rely on the listener-controlled spelling system as her primary means of conveying novel information not easily determined via yes/no questions. Upon the Easy Talker's availability, an assessment with it revealed more accurate letter/word/message selection than with the Handicapped Typewriter program. She was able to use it even when her glasses were unavailable to her, and when involuntary spasms turned her head away from the computer monitor.

Recently, she has begun to utilize it in her school environment with further training conducted by her special education classroom teacher. In addition, assessment with a portable version of this augmentative communication system currently under development has yielded positive initial results.

DISCUSSION

The clinical application of this type of augmentative communication has significantly improved the communicative ability of the previously discussed individuals and has demonstrated potential for facilitating the expression of other nonspeaking individuals with various other physical disabilities. Two additional nonspeaking clients at the center were evaluated with the Easy Talker program. Following assessment and training, one of the clients diagnosed as having dystonia musculorum deformans and who exhibited involuntary eyelid closures or spasms, achieved good success in producing simple sentence messages. Unfortunately, his neuromuscular condition worsened before funding for the augmentative communication system was acquired. A second user of the program with multiple sclerosis and mild to moderate visual problems is currently being trained in his home, using an Apple IIc computer without the speech synthesizer. Although the auditory feedback appeared to increase his potential for its use, his family's limited financial resources has resulted in his decision to master the system with reliance solely on the large, enhanced characters. The speech synthesizer will be added should this current configuration prove unsuccessful. Results of his intervention program are not yet available.

The major disadvantage of this auditory scanning program is that its present compatibility is solely with nonportable computers, with the exception of the Apple IIc which is semi-portable. The addition of an abbreviation-expansion feature to the program would serve to increase the user's communicative rate which has been historically slow with row-column scanning procedures. Preliminary investigation thus far has indicated that these objectives do not appear insurmountable. Plans are underway to develop a modified version of the auditory scanning program that can be utilized with one of the commercially available laptop computers and portable speech synthesizers.

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Computer Aided Assessment for the Selection of Augmentative Communication System Characteristics

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ABSTRACT

A software package has been developed that fulfills part of the need to provide a systematic assessment of the characteristics of devices intended for augmentative communication systems in order to optimally match those characteristics to the goals and skills of a disabled individual. The package is composed of four sequential blocks: practice using target letters; target word; vocabulary manipulation; and input acceleration. Data are collected for each block that reflect both speed of access and accuracy for a number of single and multiple switch scanning methods as well as direct keyboard entry. Its use in an assessment setting provides documentation of client performance relative to proposed system characteristics.

INTRODUCTION

This paper describes a software package developed for the Apple IIe computer which is used to assess a client's ability to select and manipulate text in a manner consistent with the use of augmentative communication systems. This computer was chosen because of its wide availability in special education and rehabilitation settings. The program described in this paper and companion programs for determining physical selection abilities and for training clients in augmentative communication skills are available through commercial sources. This program is designed to follow an assessment in which a client's ability to physically select characters using either a keyboard, a single switch or a switch array (e.g., a joystick) has been determined. We have also developed software which addresses this type of assessment (1). These other programs use non-text stimuli as targets for the client to select. This insures that physical skill is addressed rather than a combination of physical, cognitive and language skills being combined. The program described in this paper is based on a set of device characteristics which identifies those features of augmentative communication systems which are most critical to successful use of these systems (2). These characteristics place device features in relation to each other and allow choosing devices which meet client's goals and are consistent with their skills.

In order to separate physical selection skill from text generation skill, we have included a carefully designed progression from selection of marked keys or targets (included in our keyboard and switch assessment programs) to selection of target letters, target words and "free text" included in the Device Characteristics Assessment Disk I (DCAD I) described in this paper.

SYSTEM STRUCTURE

The (DCAD I) is a completely menu driven system divided into three primary components: system configuration; testing; and data. Each of these components and their respective secondary and tertiary levels are described below.

System Configuration

The first selection from the main menu is System Configuration. This is a menu that allows the clinician to select the client interface (physical selection method), the text selection method, and the selection method characteristics. The latter two comprise the cognitive selection method. The client interfaces available in DCAD I are single switch, dual switch, multiple switch (4 or 5), and the Apple keyboard. A single input box is used to connect all switches to the Apple gameport for testing purposes. The text selection methods available are direct selection (Apple keyboard), single switch linear group/item scan, single switch row/column with an adjustable acceptance time, and four switch directed row/column scan with either a fifth switch for "accept" or an adjustable acceptance time. Single and dual switch Morse code methods are also available. The selection method characteristics are a set of system variables that determine the characteristics of the text selection method, including array type (alphabetical or statistical arrangement), scan rate, acceptance time, and switch release time.

Testing

The next selection from the main menu is Testing. This menu allows the clinician to select one of four sequential assessment blocks: Practice using target letters; Target Word; Vocabulary Manipulation; and Input Acceleration. Each block has its own menu that allows the clinician to start the particular test or change the current selection method characteristics (e.g., the scan rate can be changed without having to go back to the System Configuration menu). The Input Acceleration block is composed of two separate tests: Number Encoding; and Abbreviation/expansion. The Target Word and Input Acceleration blocks also allow the clinician to select the cognitive word level to be used in the respective tests, grades 2, 4, 6 or user defined. The user defined word level can be customized in that it allows the clinician to use his/her own letters, words, or short phrases (up to 15 characters).

Data

The third selection from the main menu is Data. This menu allows the clinician to obtain a hard or soft (on the screen) copy of the data collected from the tests. Information about the client (e.g., name, client #, etc.) is entered into the system from this menu. Data can be displayed from separate tests (e.g., only from Target Word or only from Number Encoding), or a formal printout of the client information and all test results can be generated for the client file.

ASSESSMENT PROCEDURES

Software Characteristics

The symbol system for this software is restricted to Apple's upper case, 40-column characters on a transient display (monitor screen). This also restricts the software's applicability to clients who can recognize those characters and choose a matching one from a screen or keyboard array of characters. This program emulates scanning methods and array arrangements used by commercially available systems where possible in order to ease the transition from an assessment setting to actual system use.

The concept of encoding is addressed in the Input Acceleration block and in the use of Morse code. Some auditory feedback (three random tones) is provided during character matching tasks.

The vocabulary size is based on a limited selection of words from the three grade levels, and user defined vocabulary allows some expansion to more complex words or short phrases; less complex strings of characters can also be specified. The Vocabulary Manipulation block allows selection of alpha-numeric, punctuation, CONTROL, backspace and RETURN characters. Simple editing skills can be introduced and tested. The alphabetical and statistical arrays offer a simple way to test and document the usefulness of frequency of occurrence character arrangements.

Assessment

The use of DCAD I in an assessment setting is very flexible. It is most efficiently used during the selection of desired augmentative communication system characteristics in order to test their appropriateness. It can also be used during a cognitive/language evaluation to test the feasibility of alpha-numeric, 40-column sized symbols. The automated data collection of this software allows the clinician to focus on other aspects of the client's behavior or performance during the assessment.

Typically, a clinician will have initial ideas concerning potential physical and cognitive selection methods. Our keyboard and single switch assessment programs address the physical skills and various assessment methods for determining cognitive and language skills have been described (3,4,5). The initial system characteristics can be setup from the System Configuration menu. Then, the Testing menu is accessed, and the Practice block is selected. Five letters are presented on the screen. The client attempts to match them using the system simulator. The clinician can stop this test (and all other tests in DCAD I) at any time by pressing ESCAPE. Some of the selection method characteristics (e.g., scan rate or switch release time) can be adjusted at this point if required. At the close of the Practice test, the clinician can either access the Data menu to review the results or on to the next block in the sequence (Target Word).

The Target Word test also presents a string of characters on the monitor that are to be matched by the client using the system simulator. The clinician can select from three predetermined cognitive word lists (grades 2, 4 and 6) or can make up a custom word list (user defined). Each list consists of five words or character strings. The test is completed when five such strings have been matched. Also, specific character strings can be used, for example, to determine if there is a motor/perceptual problem with accessing keys on the keyboard to the left or right of mid-line or to determine if there is a visual/perceptual problem with accessing characters on a row/column screen display to the left/right or higher/lower than mid-line. Again, the clinician can either review the current results or continue with the next block (Vocabulary Manipulation).

The Vocabulary Manipulation block lets the client enter alpha-numeric and CONTROL characters as well as use RETURN and a destructive backspace. Data are collected that describe the input rate, which makes this a good test for the usefulness of frequency-of-occurrence array arrangements. Simple text editing skills can also be assessed here.

The last block in the sequence is Input Acceleration. It is composed of the number encoding and abbreviation/expansion tests. The clinician can again select a predetermined word list or make up a custom list. Input rate data are collected. If the use of words or phrases between these two tests and the vocabulary Manipulation test are coordinated, a direct comparison of the data can be made. Conclusions can then be reached concerning the appropriateness and effectiveness of encoding schemes to increase the rate of communication.

DATA

The data that are collected during each of the tasks in DCAD I reflect both accuracy and speed of access for the physical and cognitive selection methods that are addressed. They can be used to track a client's use of the proposed system over time provided that systematic assessment procedures are followed.

The data collected for the Practice test are number of errors/letter, time taken to match each letter, and up to the first five incorrect characters selected for each character to be matched. The latter data are useful in determining if there is a pattern to the incorrect characters selected.

Target Word data include total number of errors/word or phrase, total time taken to match the word or phrase, and the first five characters selected for each character of each word or phrase. Again, the latter data aid in determining patterns in wrong-key selections, especially if a custom character string is used to test certain areas of the cognitive selection method character array.

The data collected during the Vocabulary Manipulation, Number Encoding and Abbreviation/expansion tests are the same: the total number of characters selected; and the total time taken to select those characters. A record of the actual characters selected is not kept. These data allow a direct calculation of input rate (characters/second) and an estimation of words/minute.

SUMMARY

The program described in this paper provides a systematic approach to the assessment of a client's ability to generate text in a manner consistent with the use of augmentative communication systems. The text usage level is variable to accommodate to the language skills of the client. In addition the software allows assessment of the client's ability to use input acceleration methods typically found in augmentative communication systems. By presenting these features in a simulated format, it is possible to assess their value separate from the other features which a device may have. This avoids the confusion which sometimes arises when a client is confronted with a complete system which has many features in addition to the one being assessed. Often client's will attend to the size, color or output mode rather than to the manner in which text is entered and manipulated.

ACKNOWLEDGEMENT

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A RUGGED VANE-TYPE BREATH ACTUATED CALL SWITCH

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ABSTRACT

One of the most perplexing problems in the nursing care of the severely physically disabled is the inability of some patients to use a standard nurse call switch.

One alternative is the vane-type breath actuated call switch. Since no contact with the patient is required, it is easy to setup. It is, however, very fragile and easily damaged. It is also somewhat sensitive to stray air currents.

We have overcome these disadvantages by placing the switch in a specially designed housing. Two versions have been fabricated. They have been in use for nine months during which the first received minor damage and the second no damage after rough handling. The second configuration of this switch is now our primary alternate call switch.

INTRODUCTION

One of the most perplexing problems in the nursing care of the severely physically disabled is the inability of some of the patients to use a standard nurse call switch. If no alternative is available, the patient must be continually monitored by the staff. This results in very inefficient use of time. The patient is frustrated by the inability to call for help at the time it is needed.

In some cases, the standard switches can be adapted to the patient. When this is not possible or practical a special switch must be constructed for that patient. The positioning of these switches relative to the patient is usually critical. In many cases they are very fragile and prone to damage by rough handling. They can also be quite expensive.

The ideal call switch is one that can be used by any patient regardless of his disability. It should not have to be adapted to the individual, it should be set up easily without the necessity of critical positioning, and it should be rugged.

BACKGROUND

For many years there has been a commercially available switch meeting most of the above requirements. It is an "airflow interlock switch", one of the manufacturers being Rotron, Inc.[1] It is used to detect when a blockage in an air filter causes the airflow in an air duct to be reduced below a critical value. It is composed of a sail-like vane made of thin stainless steel connected by a thin stiff wire to a low torque rotary snap-action switch (Fig. 1-A). As long as the airflow remains above a predetermined rate the pressure on the vane will keep the switch closed (Fig.1-B). When the airflow drops due to a blockage, the switch then opens thereby turning off the air blower in the system (Fig. 1-C).

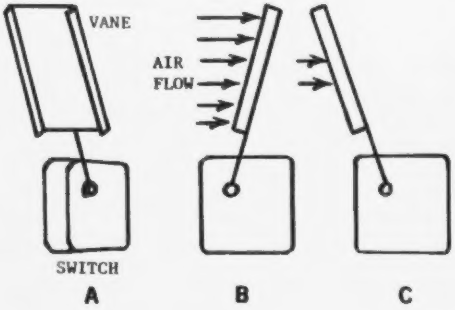

Figure 1

It was discovered that these switches made very nice breath actuated switches (not to be confused with sip and/or puff switches). A breath actuated switch is one which is actuated simply by the patient taking a breath then blowing on the vane. The airflow generated by the breath moves the vane thereby closing the switch. If the vane is large enough, very little effort is required on the part of the patient.

If a commercial switch is not available or not suitable, one can be easily fabricated. All that is necessary is a low-torque snap-action switch which is available from several manufacturers. The vane can be made as large as necessary and of various materials as long as the mass is not too great.

These switches are easily set up for the patient. Since the patient merely blows onto the vane to actuate the switch, no patient contact is required. It can be placed several inches from the mouth. Only patients with extreme respiratory problems, those without sufficient lip control, or those with a cognitive dysfunction are not candidates for the switch. For these patients a more exotic form of switch is usually necessary.

The major disadvantage of this type of switch is that the design which makes it very sensitive also makes it very fragile and easily damaged. In its industrial use, it is protected because it is inside of the air duct which it is monitoring. When used with a patient it has no such protection. Therefore, its useful life in a hospital setting is short. As a result, it is rarely used. Another disadvantage is that it is somewhat sensitive to stray air currents in the room.

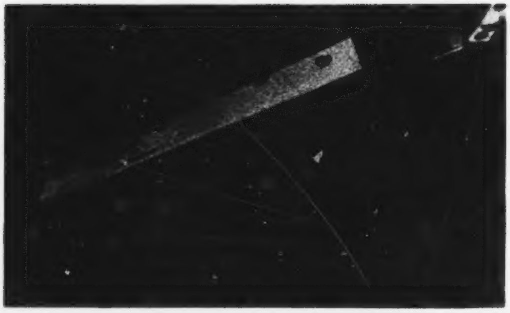

Figure 2

Figure 3

METHODS

We have overcome these disadvantages by placing the switch in a specially designed housing. Two versions have been fabricated and put into use. The first configuration protects the vane (the most fragile component) on four sides, thus leaving the front and back exposed (Fig. 2). This is the most sensitive configuration, but the vane is still vulnerable to sharp objects. In the second configuration (Fig. 3) the housing protects the back of the vane as well as the four sides. Perforations in the back of the housing (in the area of the vane) allow air to escape. The front of the vane is protected by a fin arrangement which also channels the breath onto the vane.

Figure 4 shows the arrangement of the components. The switch is a Cherry # E51-00T.[2] The vane is made of a 1 ¼ and 2 in. piece of .001 in. brass shim stock. Brass was chosen because it is easy to work with, holds its shape well (even at this thickness), and is easily soft soldered. The wire is supplied with the switch. As supplied it is straight except for the end which is shaped to snap onto the switch rotor. It must be formed as shown in Figure 4. The end of the wire to be connected to the vane must be tinned using an acid flux. Once it is tinned and washed, a non-corrosive flux can be used to solder it to the vane. The amount of solder should be kept to a minimum to keep the mass of the vane to a minimum.

RESULTS

One major effect of the fins is to alter the sensitivity pattern of the switch. As shown in Figure 5-A, when plotted with polar coordinates the sensitivity plot describes a cardioid pattern. The sensitivity at 90 degrees is half of that at 50 degrees and 130 degrees. This pattern is actually deceiving because it was made using a blower source with a nozzle opening of 7/16 in.. The actual breath pattern is more like what is shown in Figure 5-B. The outer fins will channel air onto the vane that would otherwise miss it.

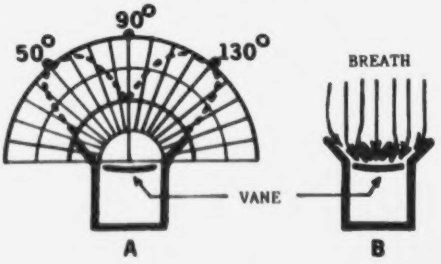

Figure 5

In actual use, the switch is fixed to a gooseneck which is in turn fixed to a stand or to some part of the bed (as in Fig. 6).

Figure 4

Figure 6

Due to the mass of the vane the switch is somewhat position sensitive. In Figure 7, A through H show the switch rotated around its vertical axis which is in a horizontal plane. I through P show the switch rotated around its horizontal axis which is in a horizontal plane. H-B, D-F, N-P, and J-L show the preferred positions of the switch for the most reliable operation. Positions F-H, and L-N make the switch less sensitive. Positions B-D and P-J make the switch more sensitive but also more likely to get "hung up". This means it will not reset after the breath is discontinued.

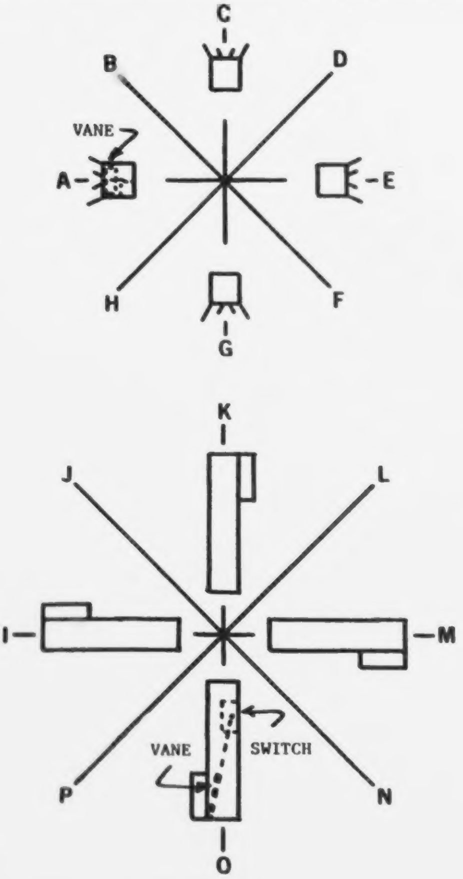

Figure 7

This is particularly true in positions C and I. This, however, is a fail safe condition because the circuit remains closed until some one physically resets the switch. Under certain circumstances this could be an advantage.

We have found the switch takes much less effort to operate if the patient makes an explosive P sound rather than just blowing onto the vane. Such sounds as "poo" or "par" will operate the switch quite reliably.

DISCUSSION

The housing does reduce the sensitivity of the switch. However, this is easily compensated by placing the switch a little closer to the patient. It is a small price to pay considering that the switch is now extremely rugged and much less vulnerable to stray air currents. As of this writing the switches have been in constant use by various patients for nine months. Version one received minor damage but it is still operating. At this time, to our knowledge, no version two switch has been damaged. The switch mounting fittings, however, have been damaged. This indicates that the switch has been exposed to rough handling.

The only problem we have had with the switch is that after prolonged use the wire bends in such a way that it will strike the stop before the switch is actuated, the result being that the switch becomes inoperative. This is not a sudden occurrence. The switch acts erratically before it stops working. If the switch starts acting erratically, it becomes necessary to either readjust the stops or reshape the wire. We believe this problem can be eliminated by more careful forming of the wire and stop adjustment at the time of assembly.

CONCLUSIONS

We have designed a rugged vane-type breath actuated call switch that is easy to setup and can be used by all but the most severely involved rehabilitation patients. Version two of this switch is now our primary call switch for patients who cannot operate conventional nurse call switches.

FOOTNOTE

1. Rotron, Inc. Woodstock, N.Y. 12498

2. Cherry Electrical Products Corp., Waukegan, Illinois 60085

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EXPERT SYSTEMS APPLIED TO REHABILITATION ENGINEERING: A NEW APPROACH TO THE EVALUATION OF CONTROL

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ABSTRACT

An expert system has been developed to aid the evaluation for control of assistive devices. The expert system models a systematic approach to identify controllable interfaces (Barker and Cook, [1]). Developed at the Expert Systems laboratory at the University of California at Berkeley, ADIS (the Assistive Device Interface Selector) is being tested at the Children's Hospital at Stanford. The source of knowledge and domain expertise is based on the clinical experience of the staff at the Rehabilitation Engineering Center at the Children's Hospital at Stanford.

INTRODUCTION

Disabled individuals use control devices which enable independent mobility, communication or control over their environment. Many practitioners (e.g. speech therapists, special education teachers, occupational therapists) are conveniently located near clients who need an evaluation to identify appropriate controls, but only a few possess the expertise of a skilled clinician. This places a time demand on the expert who must travel to non-local centers to perform an evaluation, as well as hardships on the clients who must travel at lengths and costs to centers offering these unique services. Several attempts have been made to systematize and optimize the evaluation process [1,2], but the decision-making still relies heavily on the expertise gained through clinical experience. It is difficult for a novice to make the proper decisions along the assessment path that both minimizes the number of tests the client must perform and results in the selection of an appropriate device. We propose that local practitioners given the necessary tools could evaluate and identify assistive devices for their clients if provided with decision-making assistance.

The new emerging technologies in artificial intelligence make the development of an expert system tool for control decision-making in rehabilitation engineering feasible. Expert systems or "computer-based programs that simulate human reasoning" have been shown to be effective in solving problems involving selection and classification. The expert system, ADIS (Assistive Device Interface Selector), has been designed to aid the identification process for the evaluation of control. The system provides that expertise necessary to select control interfaces so practitioners in local schools or other settings can conveniently acquire an initial recommendation.

BACKGROUND ON EXPERT SYSTEMS

Expert systems are a relatively new branch of artificial intelligence. The objective of these systems is to simulate the reasoning of a human expert in a particular problem domain solving problems human experts normally would attack. They differ from more conventional computer applications in that they can deal with non-numeric data, imitate the reasoning of a human expert and allow incomplete and uncertain information as well as explain how conclusion are obtained.

Knowledge Codification

The source of knowledge came directly from interviews with co-author Margaret Barker, articles pertaining to client assessment [1-4], as well as direct observations of client assessment. From the information, rules were written and entered into a frame-based expert system shell program capable of forward and backward chaining [6]. Knowledge or facts are captured in the form of IF-THEN rules. The IF part of the rule or premise may contain a string of AND/OR values. The THEN part or action contains one or more conclusions that can be drawn or designates an action to be performed based on the premises. A few rules from our knowledge base are as follows :

> IF ACCURACY = poor THEN TEST-A = no
> *If the client demonstrates poor accuracy in test-A,*
> *then client fails test-A and more testing is required.*
>
> IF SELECT-SPEED > 10 THEN SPEED = GOOD
> *if the client can type faster than 10 characters/min*
> *then the speed is considered good.*

In this way, both quantitative and heuristic knowledge can be codified. The use of frames allows a means of organizing the rules into natural hierarchies. Careful modeling, extraction and codification of raw knowledge into rules, better known as knowledge engineering, are necessary steps in the creation of an expert system.

PROBLEM DESCRIPTION

Our particular problem of interface-client matching is challenging not only in the field of control identification, but in the field of expert systems. There is a large number of possible combinations of anatomic sites, abilities identified with those sites as well as commercially available devices. The proper selection of a device presents a large search space of solutions. In most selection problems handled by expert systems, there is either a finite number of solutions or a finite number of symptoms or initial conditions. Given information regarding the situation or constraints to the problem, the system points to a solution. In our case, we do not want to force an interface to a client simply because it exists nor can we assume all clients will have the same abilities or preferences. The objective is to design a system which is applicable to a wide number of clients, yet provides a recommendation that is not too general.

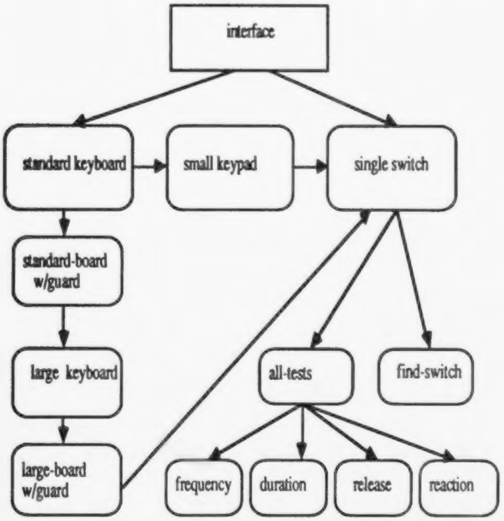
The systematic approach modeled

Barker and Cook have compiled many clinical trials, tests and observations leading to the development of a systematic approach to client assessment as well as a portable device in which to evaluate control [1,3]. Switches with the maximum number of inputs are tested first, and depending on the other parameters, skills, experience, or preference of the client, the search continues down the hierarchy. Because this problem has been well thought out and compatible with the workings of an expert system, this hierarchy of interfaces/controls has been used to model the system as well as form the basis for knowledge representation.

Knowledge representation

The rules which determine the value of a goal were grouped together into one frame using the same systematic approach developed previously. The goal of each frame was the result of a specific test leading to the solution of one of the interfaces. For instance, the goal of the large-keyboard frame is to determine whether or not a client is able to use a large keyboard, and the tests for speed and accuracy of the keyboard are contained in that frame. Using frames with specific goals and subframes with subgoals, tests for different interfaces could be separated and organized into a hierarchy (fig.1).

figure 1:



Frame Representation of ADIS

ADIS System consultation program

The system begins a consultation by first asking the test giver a series of questions regarding the range and resolution of the control site [1]. Any rules that can infer the initial values are tried until values are determined. If the information needed cannot be inferred by the system, the system asks the user for these values. With the information provided the system makes inferences that continue the consultation until a goal is reached in identifying a controllable interface. Depending on the values of range and resolution, the system determines which path to follow and which interfaces to begin testing. If the clinician believes poor scores are not an accurate representation of client abilities due to special circumstances, the system allows the clinician to fix the problem and re-evaluate the client. When the client fails certain tests, the system moves to a new test down the hierarchy. In this way, only the tests required to make a decision are given making the system both efficient to the client and the test giver.

Methods of finding a solution

Expert systems use two principal ways to search for a solution: backward chaining and forward chaining. In backward chaining, or goal -directed reasoning, the action of the rule is assumed and the premises are examined. In forward chaining, or event-driven reasoning, the given initial data will be matched against the left hand side of a rule and continue until no more rules can be invoked. In many cases, both of these approaches are used together to find a solution. In our case of matching a client to an interface, backward chaining was found to be appropriate due to the small number of solutions available relative to the number of possible client characteristics. The following set of rules from ADIS demonstrates backward chaining.

IF RANGE = LARGE AND RESOULTION = FINE
AND TEST-A1 = YES
THEN DEVICE = STANDARD - KEYBOARD

If the range of the anatomic site is large and the resolution within that range is fine and the client has passed the tests for the standard keyboard,
Then the recommended device is the standard keyboard.

IF TRACK = GOOD AND SPEED = GOOD AND
ACCURACY = GOOD
THEN TEST-A1 = YES

If the client has good track time, and the client has good speed and good accuracy in performing the speed test,
Then the client has passed tests for A1

The first rule is contained in the global frame INTERFACE and the second rule in the STANDARD KEYBOARD frame. To satisfy the conclusion of the standard keyboard, the system searches backward examining the premises searching for the values for range, resolution and test-A1. If these are known the program makes a conclusion. If the premise values are unknown, the program again searches for those rules which determine the premise values, by searching for those values in the action part of a rule. In this example, the values of range and resolution are given initial data entered by the user. The system now searches down the frame hierarchy for rules which determine the value for test-A1, and consequently forcing the system to perform the tests for A1. In this way, the program searches backward. After track, speed and accuracy measurements are taken and entered into the system, the goal DEVICE is satisfied and a conclusion is made. One advantage to this control strategy is a minimum number of questions have to be asked to determine the value of a goal. The processing time is also reduced by only trying those rules which can be inferred by the answer for the current goal. These rules may trigger other rules that are required to infer intermediate results. This continues until a value is needed that can be calculated or that the user can be expected to supply. In the case when all rules have been triggered and no more questions can be asked to acquire values, and yet the goal has not been achieved, then a conclusion is made that the system was unable to make any recommendations.

Design considerations

Quantifying parameters that are qualitative in nature such as fatigue, learning, strength, and coordination makes an expert system of this sort difficult to encode due to the fuzziness of these parameters. Some parameters are naturally transient and unpredictable. By carefully designing the questions asked to the user, many of these parameters can be more accurately represented. For instance, instead of asking the user, "Does the client have good strength?", a better question and measure would be to ask,"Can the client activate a tread switch ?", using inherent switch characteristics as a measure of force. The system was designed to be user friendly to both the client and clinician allowing natural dialog and answer. Explanations are provided of how to give the test or why a specific question is being asked. The user can also review the inferences that were made to arrive at the decisions.

System hardware

The expert system was prototyped using the Texas Instruments Personal Consultant Plus System [5] and runs on IBM XT, AT personal computer, TI Professional Computer series, or TI Explorer AI Workstation. By implementing the software on a personal computer, the system ADIS becomes more portable during the test phase as well as in its final application.

FUTURE DIRECTIONS

Prototyping an expert system for interface assessment is only the beginning of the design process. Like any tool or instrument, ADIS must be continually tested in the field. Feedback from the users as well as the clients is essential to the design. It is hoped that ADIS can be implemented to assist in the identification of functional anatomic sites. Also, interfacing the Control Evaluator with the system would allow measurements to be placed directly in the computer and evaluated by the system. Like all expert systems, ADIS can always be improved by building the knowledge base, revising the rules, making them more accurate, tailoring to the evaluation procedure and updating the methods and strategies of evaluation. The concept of ADIS presented here provides an introduction to perhaps a new a generation of expert systems: those which are applied to the needs of the disabled.

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QUANTIFICATION OF RELATIVE IMPORTANCE OF COMMUNICATION NEEDS

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ABSTRACT

A major component of the Tufts-MIT Prescription Guide is a Lotus 123 Spreadsheet containing formulas which embody the scoring procedure for the goodness-of-fit of each device to the client's abilities and needs. A basic problem in the development of the scoring has been the assignment of weights to needs which can be addressed by current technology. These needs differ in importance within and across clients.

The techniques developed to incorporate researcher and clinician judgment into the assignment of weights to needs, and thereby to the rating of the relative importance of device features are described.

INTRODUCTION

The Tufts-MIT Prescription Guide, presented briefly elsewhere in this volume, includes the calculation of a Benefit Score, B, representing the match between the abilities and communication needs of a client and the features and functions provided by each device. One component of the B score is the rate prediction, discussed elsewhere in this volume. The other components of the B score are the outputs of the processing of client and device information in a Lotus spreadsheet which combines information about the living circumstances and expectations of the client with stored files of device information.

The basis for calculation of B for a candidate device is the comparison of two parallel profiles which represent the needs of the client and the needs met by the device. There is a one-to-one correspondence between the items in these two profiles. For each need established as present for the client and met by the device, B is incremented by an amount equal to an importance weighting calculated for that item for the client. The items in the needs and needs met profiles constitute the bridge between the human-functional language in which the client and clinician describe the client's circumstances, and the quantitative technological specificity with which device features and functions must be defined. For example, this technique enables the system to assess and assign values to the relationship between the client's mobility and the pc board thickness of a device; the ambulatory client requires a device with excellent durability, which has obvious implications for pc board thickness.

The Needs Questionnaire is used to elicit information which touches on the client's speech, position and mobility, device operation possibilities, attitudes, preferences, activities, environment, availability of professional support and the people with whom the client interacts. It contains 155 items, each with 2 to 6 response choices.

The client information is processed first by a set of formulas which determine whether each of 91 needs identified are present or not for this client. A second set of formulas uses the information collected from the Questionnaire to assign a preliminary importance rating to each need. These formulas award a score of 10 (maximum), 2 (moderate) or 1 (default value) to each need depending on whether the client's activities, interests, etc. make it highly important, moderately important or relatively unimportant for the selected communication aid to fulfill this need.

Some of these formulas are quite simple in structure (e.g., if x, then number) and others are more complex (e.g., if a and (b or c or d), then number n; otherwise, if e and f, then number o; otherwise, number p). Many more than 200 judgments (equal to roughly one simple condition for each of the approximately 200 formulas in this component of the system) are expressed regarding the presence and relative importance of communicative needs which can be met by current communication device technology.

To arrive at scoring decisions, each need was treated as a separate problem. All circumstances that could result in an outcome of greater than minimum importance were assessed. The circumstances which could justify its being maximally important were reviewed, and the relevant questionnaire answers noted in the formula. The formula was then constructed so that it looks for the answers to these crucial questions first. Next, the responses or combinations of responses were listed which would warrant according a moderate rating. The formula looks for the conditions for rating 10 first, then if none are present it goes on to check for answers warranting 2, and if these are not found, it awards the default value.

The list of needs is grouped into 14 "functional categories"; for example, the category of "operational flexibility" includes presence of auditory feedback, tactile feedback, independent operation (i.e., on/off control imposes no greater motor demands than device operation), adjustable dwell/scan time, and the range of control modes possible (e.g., hand, lightpen). It is evident that assigning weights to each need individually biases the process of device matching in favor of functional categories which include many needs. Since needs were identified as communicative function gaps which could be filled by technology, rather than as basic components of human communication, an artifactual and arbitrary bias would be introduced into the device matching process if weights were not further modified.

For this purpose, a technique was devised to elicit judgments from clinicians which could be used to modify the scoring. Several experienced clinicians were asked to rate the importance of each of the functional categories on a 10-point scale, for each of four artificially constructed client profiles. These patient profiles differed in respect to a small set of characteristics which were expected, based on earlier research (Goodenough-Trepagnier & Felts, 1986), to enter into clinicians' importance judgments: age, stability, educational or occupational plans, presence of some usable speech function, supportiveness of people around him/her, interest in communicating and attitude to using technology.

Clinicians were asked to think in terms of a baseline level of function, individually defined for each category. They were asked how much improvement of the client's communication success would be gained by increasing the level of that function to a maximum, also individually defined for each of the functional categories. For example, the baseline level for "reliability" was "Device requires factory repair if moisture or dirt gets into it," and the maximum was defined as "Device survives spills, dirt, without need for factory repair"; for "output features", baseline was "Device is inert board (no independently controllled output)", and maximum was "Device has full range of auditory and visual output, under user's control".

Clinicians' responses were analyzed in the following manner: inter-respondent agreement was determined by computation of a Pearson r across categories, between members of each pair of clinicians. Ratings to be used in the Benefit calculation were obtained by averaging ratings awarded by members of the subgroup of clinicians who correlated significantly with each other.

Given constraints of feasibility, the "patient profiles" could not vary each of the important characteristics of clients independently of the others. For example, youth, stability, educational prospects and ability to produce some speech were grouped together. Inference and discussion with the clinician respondents were used to relate patient characteristics to functional category importance ratings. For example, the high rating given to the functional category of operational flexibility when the patient was characterized as over 45, medically deteriorating, not having educational or occupational plans and nonvocal, was attributed to the second of those characteristics, deterioration.

Functional category weights specific to clients sharing certain characteristics were determined, and incorporated in the Lotus formulas. The patient-profile-determined category weight is assigned by a formula wyhich checks the responses to questions concerning the characteristics which the clinician respondents based their judgments on. In this case, the formula looks at the response to the question about stability or improvement, versus deterioration. Unless the client's physical condition is considered stable, the needs in the functional category of operational flexibility receive in total a category weight of 9.

The functional category weights determine the size of the 'pie wedge' (where the pie is the total maximum Benefit score) e assigned to each category. The individual needs scores (10, 2, 1 and 0) assigned by the needs and need weights formulas determine how much of each category's pie wedge is added to the score. For example, if 4 out of 5 of the needs which make up the functional category of ease of learning for the receiver are each awarded a score of 10, the score for that category is 80% of the total score possible for ease of learning for receiver. The scores computed for each wedge are totaled to make up the Maximum Benefit score, the highest score a device could obtain for that client. Scores actually obtained by each device being considered are compared, then, against each client's individual Maximum Benefit score.

It is evident that the most reliable method of obtaining relative ratings is via a paired comparisons technique (Kreifeldt et al., 1984). Such an approach is clearly not feasible with 14 objects (the functional categories) to compare, for each of 4 client profiles, much less for the full set of 91 device functions. The problem is further complicated by the need to compare ranges of device-provided function, going from a baseline level to a specific, high level of one function, versus doing the same exercise with another function, to compare the two improvements in terms of which would be more important to promotion of successful communication by the client. The high level of agreement obtained between experienced clinicians, and their comments when questioned about how they found the technique, strongly suggest that the task was feasible and that they interpreted these concepts in a similar manner to each other and to the developer's intent.

Data presented elsewhere in this volume (Goodenough-Trepagnier, et al., 1987) provides some validity data bearing on the Prescription Guide as a whole. Ten experienced device users were also asked explicitly to score the importance of the features of the devices they used, and desirable features which their devices lacked, by means of a 4-level scale (EXTREMELY IMPORTANT, MODERATELY IMPORTANT, NOT VERY IMPORTANT and NOT NEEDED AT ALL). Users' explicit judgments agreed with the system's assigned weights (derived from the individual needs and need weights formulas and modified by the category weights) significantly in 19 / 20 cases (range: from 60 to 80%). Agreement with formula outcomes was better for features with which subjects had personal experience than for features not present on their devices.

These results from experienced device users provide additional support for the validity of the knowledge base and importance weighting methodology incorporated in the Prescription Guide. This approach will be used in the next phase of work to extend the system to cognitively involved and young communication device users.

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APPLICATION SOFTWARE: A NEW CONCEPT IN AUGMENTATIVE AND ALTERNATIVE COMMUNICATION

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ABSTRACT

Electronic augmentative and alternative communication (AAC) devices are now well into their second decade of evolution. The last few years have produced a variety of vocabulary organization systems including levels, number and letter codes (abbreviations) and semantic coding. Frequently, those that offer the user the highest potential for personal achievement also impose the greatest burden of time and understanding on the AAC clinician. Further, the low incidence of need often precludes the development of high levels of application expertise on the part of the local AAC clinician. This dilemma has led to the need to offer application software developed to meet the needs of specific groups of AAC device users. This paper describes the application software format being used by a leading manufacturer of AAC devices. The software packages consist of several components including a data disk, a manual, an overlay with symbols and a vocabulary planning chart. The programs are authored by leading AAC clinicians who have developed expertise with a particular population.

INTRODUCTION

Until recently, the evolution of electronic communication devices has been primarily a matter of continuing technological development. Early devices concentrated on addressing the physical access issues and had simple outputs: an indicator light or single letter display or printer. Early synthetic speech systems had small fixed vocabularies. Selection systems and outputs have continued to improve through technological advances and the future promises further improvements. However, the limitations of technological development are becoming apparent. It has become clear that other programmatic issues must be addressed to continue to advance the state of the art of augmentative and alternative communication.

As the technology permitted, devices became available that allowed the storage of vocabulary items of frequent value to the user. The issue then became one of selecting the vocabulary and organizing it in a way that it could easily and effectively be retrieved by the user. In his keynote address given to the Fourth International Conference on Augmentative and Alternative Communication last fall at Cardiff, Wales, psycholinguist Crystal (1986) suggested that vocabulary organization is second in importance only to vocabulary selection in the application of an AAC system. Further, he stated that semantic organization is the only approach that makes any sense at all. Minspeak is a semantic vocabulary organization system, having replaced levels and locations, number coding and letter coding (abbreviation) in most AAC applications. Minspeak has proven to be the system of choice in cases where the potential for client achievement has been anything higher than the lowest level and the AAC clinician has invested in the education needed to understand the system.

THE PROBLEM

A characteristic of the field of augmentative and alternative communication is that the incidence of need is so low that there are few clinical experts available. Further, the experts who are available may have only had experience with a particular group of clients.

Minspeak gains its superior performance through linguistic sophistication. It is a relatively new concept and many clinicians have yet to learn of its power and become proficient in its application. The incidence of need issue above has further limited the number of Minspeak-competent clinicians. Other systems, although more limiting to the client, are easier to understand and apply and are thus occasionally used in place of Minspeak. Clinicians who are truly familiar with Minspeak recognize it as powerful beyond the previously available alternatives. This higher potential demands a more thorough application. One expects more of the system and is thus driven to get more. However, these clinicians still face a formidable task in the application of the system. While the aspect of vocabulary selection is essentially the same for all systems, the issues of symbol set development and vocabulary organization and coding require an extra level of commitment to the client. For the authentic clinician, this is not a deterrent, but it does represent significant time and effort. Even in the best of situations, clinical time is scarce for AAC clients and it seems wasteful to be using it for routine activity.

Additionally, as the true nature of the field becomes known, it may well be that many clients will never have available the services of a clinical expert.

THE SOLUTION

A partial solution to the above problems is to offer application software for use with Minspeak systems. The spectrum of AAC clients is dividable into specific categories. A clinician can select a software package that most closely matches the abilities and needs of the client and then tailor it to be an exact fit.

The software package includes the following components:

- Disk
- Vocabulary Planning Chart
- Manual
- Overlay with Symbols.

Each of these is reviewed in detail later in this text. The package features a description of the typical client of this category.

An obvious concern regarding this approach of application software is that the client could end up with an off-the-shelf system that never gets adapted to the client's specific needs and capabilities. This is indeed a risk, but if the clinician allows this to happen, then the implementation without the software would have probably been substantially less functional than the standard package. The package encourages and guides customization.

THE ANALOGY

The problem and solution described here are analogous to the development of the personal computer (PC). When the PC was first introduced, it was a piece of hardware with an internal programming language (BASIC). Originally, no software existed. For the PC to be of value, the user had to program it. Today the PC is in widespread use. However, hardly anyone writes programs. We all buy software that has been prepared by experts to accomplish the desired tasks. We may occasionally modify a program or select options that tailor it to our specific needs.

In the field of augmentative and alternative communication, we have been offering the AAC clinician a piece of hardware with an internal vocabulary organization system (Minspeak). There has been no software. For the communication aid to be of value, the clinician had to program it. This concept of offering application software allows the clinician to invest valuable clinical time into customizing the system and training the client, rather than re-inventing the wheel.

EDITORIAL BOARD

An editorial board, comprised of leading international clinical speech-language pathologists having experience in the field of augmentative and alternative communication, has been assembled. The editorial board is given the opportunity to review each software package before it is made available as a standard product.

SOFTWARE CATEGORIES

With the help of a group from Purdue University, a system of categorizing the software has been developed. The intention is to allow the AAC clinician to select the software package that most closely matches the client to be served. The system is keyed to **age** and **expressive communication skills**.

Age

- Infant / Toddler
- Preschool
- Elementary
- Secondary
- Young Adult
- Adult
- Older Adult

Expressive Communincation Skills

- Symbol Use
  - < 15 conventional
  - > 15, no sequencing
  - > 15, sequencing
- Communicative Functions
  - Limited
  - Variety
- Traditional Orthography Use
  - Does not spell
  - Spells

Other Special Considerations

(Author enters any special considerations here)

The software package promotional material guides the clinician through the selection process by explaining in some detail each of the category classifications.

Many other factors can influence the configuration of an AAC system. Some of these are covered by including various options within each software package (different selection techniques, for example). Other special needs require specific software packages.

AUTHORS

The software authors are respected clinical experts from the client category being addressed. They are contracted to develop the software package to a point that PRC can put it into a production form.

SOFTWARE PACKAGE COMPONENTS

Disk
Each package contains a disk for an Apple II, Macintosh or IBM PC computer. The computer compatibility is specified when ordering the software package. The disk contains the system configuration and the starter vocabulary. It allows loading of the configuration and vocabulary into the Minspeak system using the Memory Transfer Interface.

Manual
The manual contains information about the system. It lists the vocabulary with justification for vocabulary selection to give the clinician a feeling for how to select additional vocabulary items. The icon set is also presented in the manual, together with rationale for selecting the set, again so the clinician understands it. The icon sequence code for each vocabulary item included is also presented in the same way. Instructions and guidelines for customizing the system for the user also are presented. Finally, strategies for training the user are included.

Vocabulary Planning Chart
A vocabulary planning chart is included to assist clinicians in vocabulary selection. A copy is enclosed in the software package and instructions for use are in the manual.

Overlay
An overlay is provided that is ready to be used on the device.

CURRENT STATUS

A half time position of Applications Software Product Manager has been created and filled. Candidates for an editorial board have been selected and are being approached. The first software package is in the final stages of development. A few authors have been recruited and additional potential authors have been identified.

SUMMARY

Application software is being offered to assist augmentative and alternative communication clinicians in the application of PRC Touch Talker and Light Talker electronic communication aids with the Minspeak vocabulary organization system. The software is created by expert AAC clinicians and is categorized to help the local clinician match to the client needs and skills. This approach is expected to improve both the quality and efficiency of applications. Another anticipated positive aspect of this program is the impact it will have on the level of expertise of practicing clinicians who deal with AAC clients. The educational value may well equal or exceed other clinical educational opportunities presently available to these professionals.

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PATTERNS OF LEARNING IN APHASICS TRAINED ON A COMPUTER-BASED VISUAL COMMUNICATION SYSTEM

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ABSTRACT

A Computer-Based VIsual Communication (C-VIC) System for aphasics is being developed at the Veterans Administration Medical Center in Palo Alto, CA. The application of microcomputer technology to this population is appealing because of the flexibility of the medium. The many options available in the design of software and the use of artificial intelligence provide the possibility of modifying the communication device to compensate for patients' limitations and facilitate patients' strengths, rather than the more traditional and frequently unsuccessful approach of trying to modifiy patients' capabilities directly. This paper presents an analysis of the patterns exhibited by aphasics learning to use C-VIC, and a comparison of these learning patterns to theories of learning in order to illuminate the nature of aphasic patients' linguistic and nonlinguistic cognitive skills. The use of aphasic learning patterns as a guide for the continued development of a usable computer-based visual communication system for sphasics is discussed.

INTRODUCTION

More than 80,000 adults acquire aphasia each year, due primarily to cerebral vascular accidents and to traumatic head injury. Spontaneous recovery is frequently incomplete. Despite speech therapy many of the individuals acquiring aphasia each year remain severely language impaired. Communication devices currently on the market are generally designed to assist individuals who have functional language skills but have sustained structural or motor impairments which interfere with speech production. Attempts to provide aphasics with such alternative means of communication have failed because they exceed the patients' linguistic and nonlinguistic capabilities or are too simplistic to allow communication above the level that can be accomplished with simple gestures and guessing routines. Aphasic individuals remain in need of an alternative means of communication.

BACKGROUND

In 1976, Gardner, et al, (1) reported that a visual communication system (VIC) allowed some aphasics to achieve a level of communication competence that exceeded their natural language capabilities. VIC was implemented as icons drawn on index cards which were arranged on a table top in grammatical sequences using a simple English-like syntax. Though subjects increased their communication competence through use of VIC, the system was rarely used by subjects outside of training sessions. Family members reported that the stacks of index cards were too cumbersome to be used in most situations and difficult for hemiplegic aphasics to manipulate.

In 1984, Palo Alto researchers adapted the VIC concept to the microcomputer medium in an attempt to reduce motoric, cognitive, and organizational demands on the user. This Computer-based VIsual Communication System (C-VIC) is described in detail elsewhere in these proceedings (2). The improvement of communication skills relative to natural language skills reported for VIC users was replicated with C-VIC users (3). C-VIC proved to have many advantages over the earlier index card version (2). As discussed below, many functions of the interface were observed to be immediately apprehended or trainable. However, certain critical functions of the interface were observed to be consistently resistant to mastery by aphasic users, despite intensive training. Subjects appeared to lack certain linguistic and/or nonlinguistic cognitive skills required for these tasks.

Current work is dedicated to ongoing modification of the C-VIC interface, including the application of artificial intelligence, with the goal of compensating for patients' demonstrated limitations and building on patients' demonstrated strengths. This involves analysis of patterns of learning and formulation of theories regarding the cognitive skills that are and are not available to subjects.

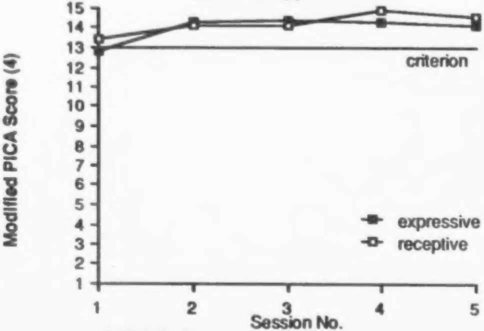
PATTERNS OF LEARNING

Immediate apprehension

Some tasks, though the patients had never previously attempted them, were performed at criterion level after a single demonstration of the task, or without demonstration.

Subject J.F., a severe Broca's aphasic, was shown individual common noun icons and asked to select one of 15 objects displayed on the table in front of him to match each icon. JF had no prior exposure to C-VIC. Figure 1 shows his performance on this task. Performance exceeded criterion level from the start. Figure 1 also shows J.F.'s performance on the expressive counterpart to the task described above: J.F. was shown an object and asked to locate and display on the computer screen the corresponding icon. Use of the computer was trained with icon matching tasks that did not demonstrate the meaning of the icons. J.F. quickly reached criterion on this task without training as well, and item-by-item analysis of the data suggests that the majority of initial errors were related to mechanical difficulty in using the C-VIC interface rather than difficulty in matching icons to objects.

FIGURE 1
Immediate Apprehension



Initial Performance with Common Noun Icons

Trained learning with retention and generalization

Some tasks required training, but once trained were generalized and retained to yield a comfortable stable performance for that task.

M.C., a global aphasic, was not successful on initial untrained attempts to perform the task described above, matching noun icons to objects. Figure 2 shows M.C.'s performance with training. Initial trials for the first set of icons introduced are below criterion level, however performance fairly quickly stabilizes at criterion level. Subsequent introduction of a second set of icons within the same task yields performance quite close to criterion level, even on the first trial. Return to the sets of items at a later date revealed retention. Though M.C. did not exhibit immediate apprehension, he was able to learn the task, generalize the learned skill to novel instances, and retain the knowledge.

M.C. exhibited this same pattern when learning to use C-VIC to name unseen objects. The trainer pantomimed the use of an object and M.C. was trained to use the C-VIC system to name the object indicated. Training and data collection were implemented using a multiple baseline single subject research design. Figure 3 illustrates his performance on this task. Pretraining baseline

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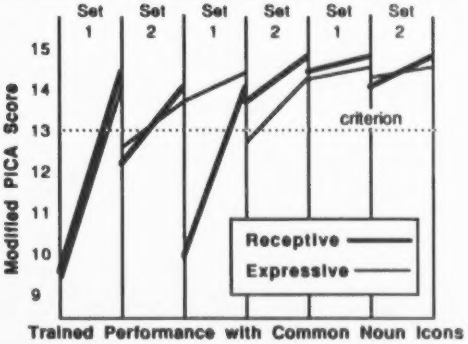
indicates consistent performance below criterion level with no trend toward eitner improvement or disintegration of skills. When Set 1 is trained, performance on this set improves to criterion level. No generalization to untrained items is observed. When Set 2 is then trained along with set 1, performance on both sets reaches criterion but there is still no observable generalization to untrained sets. Sets 2 and 3 are then trained, but additional training of set 1 is withheld. At this point performance on all sets reaches criterion level, indicating retention of the items in set 1 which is no longer trained, and generalization to the items in set 4, which never was trained.

FIGURE 2
Trained Learning with Retention and Generalization



Trained learning with retention, no generalization
Mastery of other tasks followed the previous pattern without evidence of generalization to untrained items.

This pattern was observed in two severe Broca's aphasics, J.F. and R.L., who participated in a study designed to investigate aphasics' abilities to comprehend abstract vs. concrete iconic representations of verbs (5). Subjects were required to select one of ten icons to represent a demonstrated action. Training was implemented using a small box as the object of the actions. Performance was measured in three conditions: using the box as the object of the actions as in training, using a jar as the object of the actions (never trained), and using videotaped scenes showing a variety of items as the objects of the actions (never trained). Figure 4 illustrates performance on these tasks. Again, pretraining baseline measures indicate stable performance below criterion level. With training, performance in the box condition rises to criterion. (The majority of the icons required training— for each subject only one icon was found to reach criterion level without training.) Generalization to the jar condition is noted. (The jar condition was visually very similar but not identical to the box condition. Consider the difference between opening a box and opening a jar, for example.) Performance in the videotaped scene condition never reaches criterion, despite stable criterion level performance in the box condition. Return to the task after several days revealed retention of the ability to use the icons to represent actions performed on the box and jar.

Trained learning, poor retention, no generalization
Other tasks were mastered with training, but showed no generalization and poor retention. Periodic review is required to maintain criterion level performance.

Subjects learning to use C-VIC have generally found verbs to be the most difficult category of icons to master. The use of icons within the C-VIC system differs from the use of verb icons described above in that the interface offers a selection of up to 50 verbs rather than a limited selection of ten. As discussed above, generalization is limited, and additionally, within the C-VIC system review of verbs at the beginning of training sessions is frequently necessary to re-establish previously achieved levels of performance.

DISCUSSION

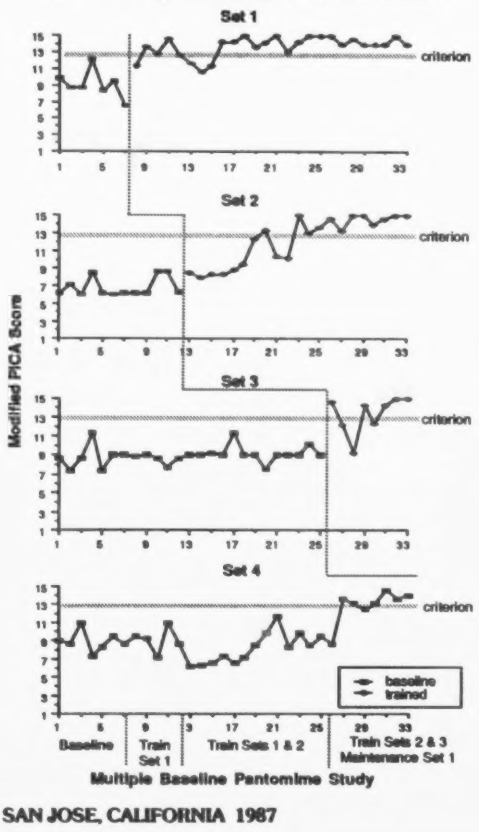
Performance of aphasic subjects is quite robust for some aspects of the C-VIC interface, i.e. some tasks are obvious without training, or can be learned, generalized, and retained. Skills discussed above which fall into this category include the ability to match common and proper noun icons to objects and *vice versa* even with novel objects and icons, the ability to "name" unseen (pantomimed) objects with icons in novel instances, and the ability to learn to associate icons to specific situations involving action (despite the abscence of the ability to discern a concept which allows generalization to novel instances). Skills not discussed above which have been informally observed to be robust include the ability to manipulate the computer interface, and the ability to use a specified order when sequencing icons.

Performance on certain other tasks is stubbornly resistant to mastery. As discussed above, this includes the ability to generalize the meaning of verb icons to novel instances. Informal observation suggests similar difficulties in using preposition and modifier icons.

What demands do the tasks which resist mastery despite intensive training place on the subjects that the successfully performed tasks do not? Or, to approach the same issue from another direction, which kind of learning is possible and what kind is not? Learning can be broken down into the following theoretical types or levels.

Paired associate (non-concept) learning
Paired associate performance requires learning a particular response for a particular stimulus. The ratio between stimuli and responses is one-to-one. No pattern is discerned which allows the performer to correctly predict future responses, i.e. generalize. The response to each stimulus within a task is learned by rote, and therefore, this is not a very powerful level of learning. The performance of subjects J.F. and R.L. on the verb study falls into this category. They were able to memorize demonstrated associations between icons and actions, but apparently did not clearly discern an underlying concept which would have allowed

FIGURE 3
Trained Learning with Retention and Generalization



them to consistently generalize the use of the icons to novel instances. It is significant to note that both the stimuli and responses for this task, processed at the paired associate learning level, are *visually based*. Subject M.C. initially appeared also to be processing information at this level when learning to use C-VIC to "name" pantomimed objects---only trained items were correct. Eventually however, he appeared to be operating on the basis of a concept which allowed him to generalize to novel instances.

Concept learning

A concept can be defined as a class of stimuli that share one or more common characteristics. Concept learning requires the learner to first determine relevant characteristics of a concept, and then respond to only these relevant characteristics of a stimulus while ignoring other irrelevant characteristics. The ratio of stimuli to responses is two or more to one: all stimuli governed by a given concept yield the same response. Understanding a concept therefore provides a logical basis for correctly and consistently producing correct responses to novel stimuli, i.e. generalizing.

Simple concepts. Simple concepts are those concepts whose common characteristics are inherent in the *visible* physical structure of the stimuli. Responses are made directly to the stimuli, the relevent characteristics are the physical properties of the stimuli itself. Comprehension and generalization of noun icons suggests the use of a simple concept. The subjects' apparently discerned the relationship between the two-dimensional line drawings and their counterpart three-dimensional objects. The relevant characteristics are inherent in the visible physical structure of the stimuli, subjects could respond directly to the stimuli with no intervening processing. Working on the basis of this concept, rather than memorizing paired associations, allows the subject to understand the meaning of new icons without training, and to use familiar noun icons to correctly label novel stimuli.

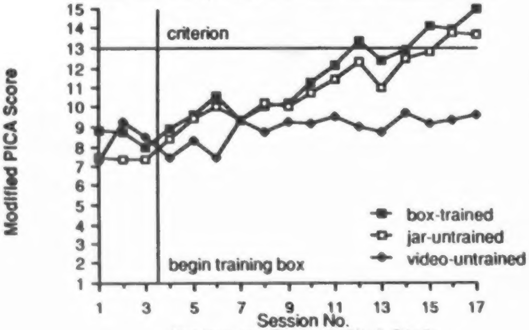
Complex concepts. Complex concepts are formed on the basis of common characteristics which are *not* part of the visible physical structure of the stimuli. In fact, for many complex concepts, the visible physical structure of the stimuli comprise the irrelevant characteristics which must be ignored. Responses cannot be made directly to the stimuli. The learner must mediate by introducing an intervening step between the stimuli and response. Comprehension of the iconic representation of verbs in the C-VIC system requires concept learning with mediation. Static line drawings of actions require the learner to recognize that the visible physical structures pictured in the stimuli (the agents performing the actions and any objects shown) are not to be responded to directly, in fact, must be ignored. Rather, an intervening step of determining what action would be occurring if the pictured agent were in motion is required. This invisible product of mediation is the stimulus to which the subject must respond. A second example of a concept requiring mediation is subject M.C.'s eventual success in generalizing the use of C-VIC icons to label *unseen* objects in response to pantomimed use of the objects. This task required M.C. to determine what object would be used in the manner pantomimed, and then select an icon to represent this result of his cognitive processing. Other subjects found this task quite easy. The fact that the subjects could perform this task, but could not successfully use verb icons is interesting. Perhaps it can be explained by pointing out that the verbs require complex conceptual thinking both to analyze the stimulus and to select an icon to label the stimulus. The pantomime task, on the other hand, requires complex conceptual thinking to analyze the stimulus only. Selection of a common noun icon for the response is done at the simple conceptual level, as discussed above.

CONCLUSIONS

Subjects exhibit stable, successful performance on tasks which require them to respond directly to visible stimuli. This includes memorized associations and the more powerful ability to perform on the basis of simple concepts. Complex conceptual tasks, which require mediation by the subjects, processing of the stimuli in some way and responding to the invisible result of this process, have thus far been demonstrated to be resistant to mastery despite intensive training, especially for tasks in which mediation is necessary for both the stimulus and response. This resistance suggests that modifying the communication device to accomodate subjects' capabilities may be more promising than attempting to modify the subjects' capabilities directly. The computer medium is well suited to this approach.

Use of this information to guide future development of the interface suggests the need for verbs and other difficult aspects of the interface to be represented differently. An interface that interacts with, guides, and provides feedback to the user with visible stimuli that can be taken at face value is indicated. Approaches under investigation include the use of animation in verb icons to increase the salience of the action relative to the agent and objects. Implementation of artificial intelligence to create pathways to desired results and feedback about results via a series of simple decisions also appears promising.

FIGURE 4
Trained Learning with Retention - No Generalization



Abstract vs. Concrete Verb Study

ACKNOWLEDGEMENTS

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A STRATEGY AND TOOLS TO TRAIN AUGMENTATIVE COMMUNICATION SKILLS WITH SINGLE SWITCH USERS

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ABSTRACT

Some individuals must rely on augmentative communication systems to facilitate the development of expressive language. For an individual using a single switch to control electronic aids, the training of expressive language skills is complex. A software package has been developed to systematically and gradually train skills associated with making choices using a single or two switches. The user is presented with backlighted choices that are attached to the monitor screen of an Apple IIe computer. The choices are reinforceed with voice output. Step and auto linear scanning as well as auditory scanning can be trained using this package.

INTRODUCTION

Training of augmentative communication skills to children not using speech must occur early. A high priority for these children is the development of a portable augmentative communication system. The development of a communication system includes the identification of a control or interface, the training of strategies to use the control, training of vocabulary items and symbols, integration of the symbols into a communication system and training of communication skills. The training of vocabulary and symbol use begins with identification and making choices.

BACKGROUND

Prelanguage Skills and Control Selection

Before evaluating a person's ability and needs for a control or interface, prerequisite skills must be present. These skills are often referrred to as prelanguage skills and include attention, auditory and visual localization, imitation and turn-taking and cause and effect. The child must understand that he has some control of the immediate environment, that he can make something happen or functionally play with objects or act on objects. Making a choice is another skill as well as that of symbolic representation in that the child must be able to substitute meaning for a symbol. The evaluation and development of these skills can be facilitated using adapted play and toys (Carlson, 1982; Musselwhite, 1986).

Control Selection

Once a child demonstrates the existance of the required prerequisite skills, a physical selection method that can be used by a child to make selections using an augmentative communication system can be determined. A communication system can include a manual communication board or an electronic system. An electronic system is typically indicated when the user needs consistent, immediate feedback that is independent of the receiver of a message. If an electronic system is required and the child is not able to use a direct selection method, a single switch may need to be identified and control strategies developed.

The identification of a switch usually needs to be facilitated with highly motivating feedback to the young child. It is essential that the child is motivated to control a toy or another device with feedback such as a tape recorder in order to identify an anatomic site that can be consistently used. The process may require several sessions with the child trying several switches with anatomic sites that demonstrate voluntary controlled movement. A systematic method of evaluation such as that described in Barker and Cook (1981) should be used to identify an anatomic site and a control or interface.

When the most reliably and consistently used control is a single switch, scanning strategies must be trained in order to make choices. A sequential process should be used to train scanning strategies and increase the number of possible choices for the single switch user.

SOFTWARE DESCRIPTION

These programs are designed to train skills needed to use scanning communication systems and to reinforce choices made by the user with speech output. One and two switches are used to train scanning skills to make choices. These programs are intended to be used in one-to-one sessions with a parent, teacher, or therapist.

These programs can be used to select from one to four, six, or nine choices. Pictures of choices (photographs, line drawings, stickers or plastic pictures such as those made by Colorforms) should be taped to the computer monitor. The programs will light up one position on the screen at a time.

This package requires an Apple IIe, an Echo speech synthesizer and an adapter for the game port to use switches and provide output to control battery operated devices such as toys or tape recorders.

There are two types of programs included in the package, setup programs and the scanning programs. The setup programs are used to develop and store the vocabulary sets that are used with the scanning programs. The scanning programs are titled Two Switches/Two Choices, Visual Step Scan, Visual Auto Scan, Auditory

Step Scan and Auditory Auto Scan. For each of these programs, the outputs, when a selection is made, include voice output of a phrase or the activation of a toy or other battery powered device plugged into a switched output adapter for the Apple computer.

Two Switches/ Two Choices

This program is used to select between two choices. A picture of each choice should be placed on the left and right sides of the monitor. Two switches are used. One switch corresponds to the picture or selection on the left side of the monitor and the other to the one on the right. When a switch is activated, the corresponding picture is highlighted by a white square and the output is spoken or a toy is activated. The output is based on what is delineated in the setup program.

Step Scan

This program uses step or manual scanning (i.e., each time the switch is pressed, the next choice is highlighted). One to four, six, or nine choices can be put on the computer monitor. It is designed to be used with two switches. One switch moves a square to highlight a choice and the other activates the output which can be either voice or toy activation. The user must activate one switch to indicate the choice and the other switch to activate the corresponding output.

Visual Auto Scan

This program uses automatic scanning (i.e., the first activation of a switch starts a sequential scanning of choices, the second activation stops it). One to four, six, or nine choices can be put on the computer monitor. It is designed to be used with one switch. The program will start scanning when the switch is activated. When the switch is pressed a second time, the scanning will stop and the output will be spoken (or the toy activated). Scanning will resume when the switch is activated again.

Auditory Auto Scan

This program uses automatic scanning. One to four, six, or nine choices can be put on the computer monitor. It is designed to be used with one switch. When the switch is activated the scanning begins. As each selection is backlighted, the scanning phrase is spoken. Scanning of the choices continues until the switch is pressed and the selection phrase is spoken. Scanning resumes when the switch is activated again. The scanning phrase and the selection phrase can be two different phrases. Typically the scanning phrase is a key word that can be used to remember the longer or more complete selection phrase.

Auditory Manual Scan

This program uses step or manual scanning. One to four, six, or nine choices can be put on the computer monitor. It is designed to be used with one switch.. Each time the switch is activated the next choice is backlighted and the scanning phrase is spoken. The selection phrase is spoken after a user selected time period. The time period is the time since the switch was last released.

SUMMARY

This program is currently used in an evaluation and training clinic for augmentative communication skills at Children's Hospital at Stanford. It is used to train single switch skills, in communication and play therapy to develop vocabulary, symbols, language and active communication skills. The program is also used to train auditory scanning skills to individuals with visual impairments and physical disabilities.

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REPRESENTATIONS OF "VERBS" IN A COMPUTERIZED VISUAL COMMUNICATION SYSTEM

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ABSTRACT

Abstract versus concrete representations for verbs in a visual, non-verbal communication system for severe aphasics were investigated. Two patients with comparable Broca's aphasias were studied in simultaneous multiple baseline experiments. Concrete symbols were learned more quickly and generalized slightly faster to apply to new objects. However, neither abstract nor concrete symbols were well generalized to novel situations. The implications for future directions of research on visual communication systems are discussed.

INTRODUCTION

The representation of lexical items for actions or verbs appears to be a crucial element in non-verbal alternative communication systems for aphasic patients. These patients find predication, especially construction of statements about actions, particularly difficult. Investigators using both natural language and alternative communication systems for treatment of aphasic patients have noted the pivotal position of verbs and the need to re-educate these patients in their use (1,2).

The investigators of the original card-based VIC system (3) noted that the majority of the patients' errors in VIC were in using verbs. They had used abstract symbols for verbs, because they felt that these were more likely to be successfully generalized. In our investigations of a computerized visual communication system for severe aphasics, C-VIC (4,5), we have found that performance by severely aphasic patients using symbols for verbs was less accurate, less consistent and required more training than performance using symbols for nouns or prepositions. Substantial variation in performance using different verbs was also noted. As we have used both concrete and abstract representations, we believed that the differences in representation might account for some of this variation. A second, distinct problem in performance using symbols for verbs was that the patients did not automatically generalize their learning of these symbols to new contexts as they did with nouns and prepositions.

To illuminate some of the sources of variability in patient performance using visual symbols for verbs and to optimize the representation of these symbols, we have conducted experiments with two agrammatic Broca's aphasia patients using C-VIC. These patients were studied, rather than global aphasics, because while their less severe receptive deficits make teaching them new VIC symbols less arduous, they nonetheless suffer from profound deficits in using verbs. Abstract vs. concrete representations of verbs have been evaluated. Ease of acquisition, reliability of performance in structured situations and generalization to novel contexts have been measured. The results may have implications not only for the current implementation of C-VIC but also for future visual communication systems.

METHODS

Abstract and concrete representations were constructed and tested on normal language functioning subjects. For inclusion as a "concrete" representation, a symbol had to be correctly identified without cues by at least 60% of the subjects. Additionally, when presented with ten visual symbols and ten written English verbs, subjects had to correctly match the meaning greater than 85% of the time. An "abstract" symbol had to be spontaneously identified by less than 50% of the normal subjects, yet correctly matched greater than 50% of the time when a list of written English verbs was supplied. Symbols were incrementally altered to achieve these criteria and were tested on different groups of nine to ten naive subjects. Figure 1 illustrates abstract and concrete icons for two verbs.

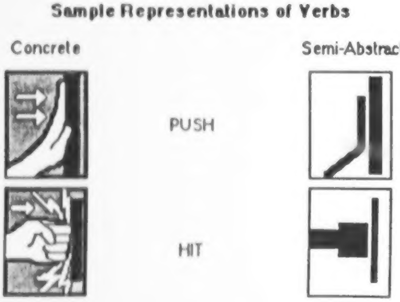


Figure 1

Two patients with agrammatic Broca's aphasias and nearly identical scores on the BDAE (6)were enrolled in a paired balanced experiment. Each subject was presented with a set of ten symbols for ten new verbs, five of which were concrete and five abstract. The sets were balanced so that verbs represented with concrete icons for one subject were represented with abstract items for the other. The two subjects were trained on the verbs in multiple baseline fashion, using only a small box as the demonstration object. Verbs were introduced in the same random order for both subjects and trained for four sessions or until subjects' performance reached criterion (100% correct use with the training object).

At the end of each training session, subjects were tested by an examiner other than the trainer, demonstrating the verbs using the small box (training object), using a jar, and with a videotape demonstration in several different contexts. The subjects' task was to identify the verb demonstrated by pointing at it on a sheet displaying all 10 icons. Each verb, including those untrained, was tested in each session with the box, a small jar, and the videotape sequence. The order of verb presentation was randomized for each testing session. Subjects' performance was scored with a modified PICA system (7).

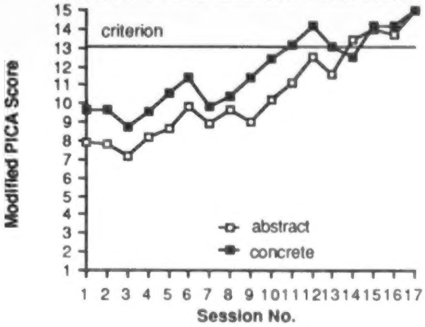
After subjects had reached a stable level of performance on all verbs (17 sessions), an attempt was made to deliberately teach generalization. In these sessions, verbs were trained with as many objects and situations as possible in the training room, but were not trained on the videotape sequences. Subjects were re-tested using the videotape sequences at the end of each session.

RESULTS

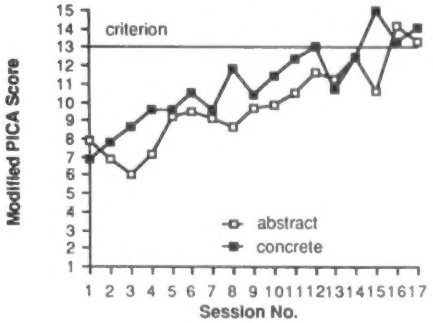
Figure 2 illustrates the composite results for both patients on the three task conditions. The use of this paired, summed data allows comparison of the effects of the concrete/abstract

FIGURE 2

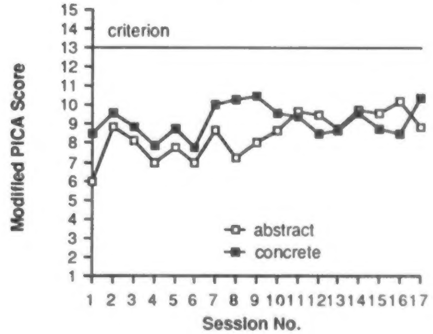
Concrete vs. Abstract Box - Mean Score



Concrete vs. Abstract Jar - Mean Score



Concrete vs. Abstract Video - Mean Score

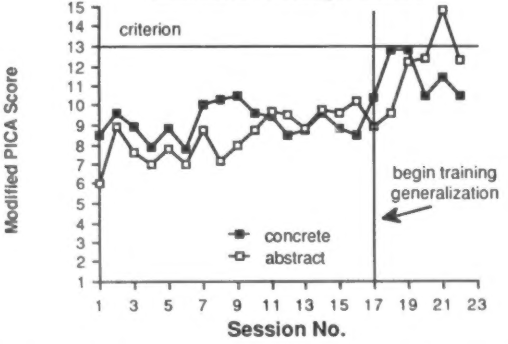


dichotomy, since the effects of individual verbs are balanced in each pair. Note that the concrete symbols were learned faster than the abstract ones and also generalized to a new object (jar) faster. After 17 training sessions, the same level of performance was achieved for both sets of symbols. Performance using an object other than the trained item was slightly less consistent than that using the trained object, but still quite functional.

In striking contrast was the relatively poor spontaneous generalization of symbols to novel contexts. The patients correctly identified the videotape sequences using concrete symbols on average only slightly better than when using abstract symbols. However, their performance identifying videotape sequences was much inferior to that obtained when the examiner demonstrated verbs with objects in the training room. Figure 3 illustrates the effects of training directed towards improving generalization: the patients' performance improved but did not reach functionally useful levels. There appears to be a slight bias in favor of abstract icons being generalized to videotape sequences after training.

FIGURE 3

Mean Score - Videotaped Scenes



Analysis of subject performance and errors with individual verbs provided additional clues to factors influencing performance. For example, the verb "to empty" was the only verb correctly generalized in describing the videotape by both patients. Unlike the other verbs in this study, no discrimination of direction, as needed to distinguish "push" and pull" or "open and "close"; magnitude, as needed to distinguish "push" from "hit"; or actor, as needed to distiguish "catch" from "throw", was necessary to use it. Both patients made errors most frequently in failing to make these distinctions.

Inclusion of some concrete detail in symbols may be problematic. For example, when we later attempted to teach generalization, our subjects had some difficulty applying the verb "to hit" to situations where a fist was not involved. Similarly, we have encountered resistance to generalizing the verb "to read", which is currently depicted as a silhouette of a person reading a book, to situations in which someone is reading a magazine or cereal box.

CONCLUSIONS

Concrete representations for verbs are learned more quickly by Broca's aphasia patients than abstract representations. An abstract representation does not significantly aid generalization of a learned symbol to novel contexts. Discrimination of magnitude, direction and actor as a component of verb selection may be particularly difficult for these patients. These results suggest that verb symbols in a visual communication system for aphasic patients should be represented concretely, but that additional cognitive aid is necessary to allow aphasic patients to generalize these symbols for use in novel, untrained contexts. Further, the precise concrete detail included in a symbol may be crucial in determining whether it will be successfully generalized.

While the present C-VIC system provides a substantial increase in communicative potential for severely globally aphasic patients, its extension into a generally useful language orthosis for patients with severe expressive deficits will require that patients can successfully apply their mastery of the C-VIC vocabulary to novel situations. Investigations using more of the computer's capabilities to provide additional cognitive aid, for example, by use of animation and contextual cueing schemes (8), are in progress. It is likely that the results obtained in studies of patients with severe expressive aphasias will also extend, in part, to patients with global aphasia and that their performance using C-VIC will also improve with increased cognitive aid.

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RPM FOR ACCESSING LARGE VOCABULARY FILES

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Abstract

This paper presents a rapid procedure method (RMP) for accessing large vocabulary files. It is suited for those who are handicapped in using a computer keyboard. An operator controlled, binary search method is described and results using it by ten handicapped subjects on a 30,0000 word vocabulary is given.

Introduction

Consider for some reason that you're handicapped in regards to being able to use a typewriter keyboard. In addition, your penmanship is bad or it is impossible for you to write. At present, you can peck at a key with a finger, toe or mouth held stick. You would like to write your Congressman a letter about support for your pet project. Now picture a computer screen. On the screen is a list of options with an arrow pointing at one of them. This particular list is the letters of the alphabet. Using your finger, toe, stick or whatever, you close the switch that causes the arrow to move through the list. The word you want is "Dear". Like in Dear Congressman, you move the arrow to D. You now close another switch. The switches could be keys, toggles, joy sticks, eye blink detectors, suck-puff pressure transducers or a sequential choice automatically stepping through on the screen. Now, on the screen, instead of the letter D, a word appears starting with D. You are now into a large vocabulary of D beginning words. Using a rapid searching method, you quickly locate "Dear" You pick the word by closing a switch. Now the word "Dear" is kept on the screen. You move back to a list of options by closing another switch. Using the same method, you pick "C" and rapidly locate the word Congressman and pick it. Continuing with this process, you add the comma; the options have a set of punctuation available as well as a choice of building a word, letter by letter, if it's not in the vocabulary. You continue in this fashion writing your letter. When it is complete, you pick a print option and your letter is printed out.

To write this letter, you've only used four switches or screen options to rapidly find words in the dictionary, build text and print out your letter. How much time has it taken? Well, of course, that depends upon the length of the letter. Also, it depends upon how you, yourself, manage the rapid search and close the switch. You can locate one word out of 4,000 in less than 12 switch closures. Six or less will usually do. What you've used is a system in which you've been in total command of a rapid method of picking words, assembling them in proper order, adding punctuation and new words and printing out the results. All you had to do was puff or blow, move a finger, elbow, shoulder or toe or any part of you that can be translated into a switch closure. What have you gained? Well, hopefully, number one is speed. Next might be properly spelled text or depending on your handicap, the ability to easily produce text. It is simple to use and you should be able to produce text within about 30 minutes of instruction.

Background

According to researchers at John Hopkins University, some 20 million individuals in the United States suffer from some handicap (1). Many of these handicaps result in an inability to communicate. Of this population, there are over 1 million children and adults unable to communicate orally, or an even greater number who have motor disorders interfering with written communication (2). In past years, individuals with motor disorders caused by disabling diseases or injury have had a difficult time communicating in written form. In the case of the multipli-impaired, there may be speech difficulties as well. The potential of the microcomputer as a device to assist in communications for such persons is widely recognized. Yet research and actual applications are still in early stages. The first systematic nationwide attempt to find software and hardware applications for the handicapped occurred only five years ago in the John Hopkins first national search for applications of personal computing to aid the handicapped (3). The goal of most augmentative systems is facilitating effective interaction between communication-impaired individuals and people in their environments.

Current text processing systems for the communication-impaired share the "effective-interaction" goal and are functional in terms of causal communication. They are adequate for the purpose of producing light text and thus meet a basic need for the communication disabled. Some examples of available text processing systems includes Seymour's Morse Code System, using standard commercial software in an Apple Computer (4). Pollack's Microcomputer with modified keyboard which stores vocabulary in memory and displays them in a 3 x 3 matrix on a CRT (5) and Waltosy's Word Plus Living Center which allows for more complete communications (6) Typically, these systems will provide thru put in the range of 5 words-per-minute. At the 1986 Closing The Gap Conference, Morse Code speeds ranging from 15 to 30 words-per-minute were reported (7). The most promising systems present the user with a CRT screen filled with rows and columns of the alphabet or groups of words chosen from alphabetical sets. The Words Plus system even provides some predictive capability in presenting a list of the words previously used after the one just chosen. The following describes a rapid procedure method (RPM) which can provide users a word processing system rapid access to large vocabularies.

Method

The kernel of the rapid procedure method for accessing large vocabulary files provides for a method of storing a vocabulary and recalling it word-by-word as needed in assembling of text. Dictionary files are stored in a computer in a manner defined by the search algorithm used. Ideally all words of interest to the operator are contained in the files. The system, as tested, contained 30,000 words alphabetized and stored in twenty-six files based on the letters of the alphabet. Due to some initial storage restrictions, the largest word that is contained in the file is 15 characters long. The system, through a menu of options, allows the operator to pick which file to operate on. This file is activated and a word from it is presented on the CRT screen. The particular word initially presented is a function of the searching algorithm. The operator then commands the computer through a set of input controls to move through the file in a technique which is again defined by the searching algorithm. The control inputs are search up, search down, pick a word and exit the kernel process. When the desired word is located, it is stored in the system. The procedure is repeated until the text is finished. At that time appropriate punctuation can be added and the text used as desired.

It is important to note that the operator, not the computer, knows what word is desired and that the computer is being manipulated by the operator to locate this word without having to key it in.

The current version of the RPM System uses the binary search. It is important that the operator thoroughly understand what a searching algorithm does and learning the binary search is straight forward. In the binary search technique, the dictionary files are alphabetized and stored as random access files in the computer. When the operator picks a particular file, the middle word in the file is presented on the screen. The operator then commands which direction, up or down, the search should proceed in the file. A block diagram of the binary search technique is presented in Figure 1. In the binary technique the algorithm jumps through the file by taking the half of the file the operator wants to move into, dividing it in half and presenting the word from that location. This procedure is repeated until there is no more file left to half. By moving up and down, in the file, the operator can rapidly locate the desired word. In the worse case, a binary search only requires N maximum up or down commands where N is an integer and

$$2^N = X$$

Where X is the smallest number in which the file can be contained. As an example, if the file contained two hundred words, then in the worse case a maximum of eight movements in the file would be required to find the word because 2 to the eighth = 256 and 256 contains 200. Usually the number of movements required is much less than N.

For those persons who have an orthopedic handicap which prevents them from effectively using the typewriter keyboard, control inputs for operating the RPM System are simple to implement. At the present time, the system can be operated through any single switch closure or the system can be operated using four switches that can be easily arranged in a pattern convenient for the user.

The RPM kernal has been implemented on an IBM Personal Computer. It is operational with two floppy disk drives or an internal random access/memory disk system. A simple word processing system has been built around the RPM method and used to test the feasibility of this approach on ten handicapped students at Wright State University.

All of the subjects were college students who participated in the research on a voluntary basis. The subjects had a loss of arm and hand dexterity that ranged from a minor loss of control and strength to almost complete loss of movement. Of the first five, one was CP, three were quadraplegics, and one a birth defect subject. Each subject was provided with a familiarization period where they learned to use the system followed by a pre-test, three hours of learning, a mid-test, three more hours of learning, and a post-test. The familiarization period provided instruction in the use of the system and a period of time to perform a set of exercises to show that they completely understood the searching algorithm. This required approximately 50 minutes per subject. The subject would then be given a pre-test which consisted of a set number of words that the subjects were to input into the system. The subjects were timed to find the rate of input. The subjects then proceeded with six 50 minute learning periods. There were three sessions a week spread over a two week period. During these sessions, the subjects were given a predetermined test to input into the processor. The subjects were then asked to work as quickly as possible, but to try to minimize mistakes. After the third learning session, the subjects were given a mid-test which consisted of a twenty minute timed period. After completing the learning stages, the subjects were then given the post-test.

Results

The results were excellent in regards to the subjects ability to manage the search algorithm. All preferred the 4-switch control method. Their time for building text was as good or better than their previous method which was using a stick or finger to poke at the keyboard. The simple text processor was a bust as it had processing delays that produced long wait periods as the text grew. However it still produced five to seven words per minute.

Another group of five subjects were then tested on three input methods. These were single switch control, four switch control and voice control. In this group were two CP's and 3 quadriplegics. As in the previous group, the single switch closure was not well received. Two of the subjects had poor eye-hand coordination necessary to respond to a control option that was being sequenced on the CRT screen. For these two, it produced a high level of frustration. Another had no sensation in his hands. So he had to continuously watch his hands to see if he was closing the switch, trying to do that and watch the screen at the same time proved to be too difficult for a decent system thru put. A switch click might have helped. One of the subjects had very good hand eye coordination but had a tendency of hitting the control switch before the choice had been appropriately sequenced on the screen.

Moving to the 4-switch control, three of the subjects were able to increase their speeds four times that of the single switch control. One used a pointer and had problems getting the pointer off the switch in a reasonable period of time and the other had a similar problem when using his finger. Their accuracy was much better in using a 4-switch control.

For voice input the Pronounced controller was utilized. One of the quadriplegics was unable to participate during this training. The four remaining subjects all trained separate vocabularies for controlling the search algorithm and the alphabet and numbers and punctuation. Pronounce has limitations in voice recognition if the tone of the subject's voice changes much. For one subject, this proved to be so frustrating that periodically the computer got shouted at. The biggest surprise came in training one of the CP's, who is very hard to understand in normal voice conversation. For this subject, the system worked like a charm. His favorite phrase to turn the recognition system on is "Listen to me, dammit!" He had difficulty saying longer word groups such as "left-angle-bracket" which caused some frustrations and some phrases were changed, such as: fix-it for forget-it, get-lost for goodbye and I am for I'm.

Conclusions

The RPM System is a viable method for providing rapid access to large vocabularies for people who are doing text processing and have difficulty manipulating a standard keyboard. The less automated the control system, the better the subjects were at text thru put. The voice control has promise for some subjects. However, the system that was used in this test has limitations which produce user frustration. It appears that the RPM kernel would be well suited as an overlay system for standard computer packages such as Word Star, Lotus 1-2-3 and dBase 3. Research is currently being undertaken to develop this capability.

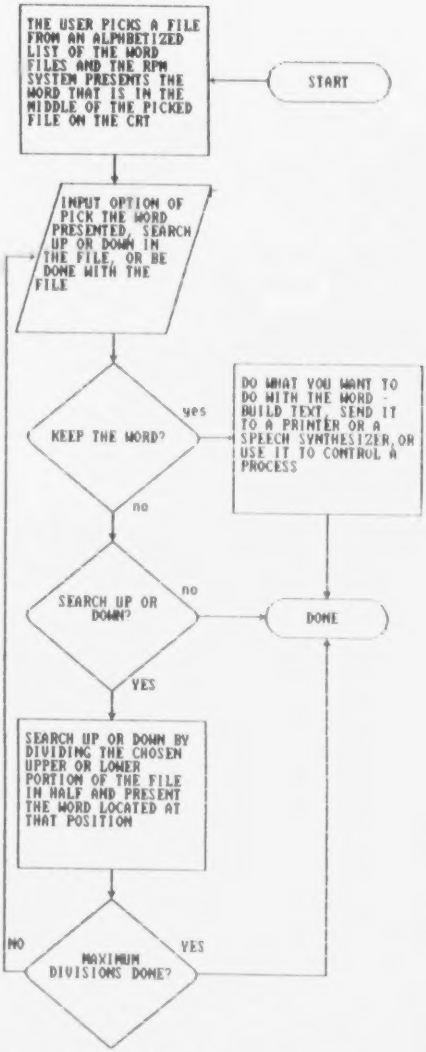
THE USER PICKS A FILE FROM AN ALPHBETIZED LIST OF THE WORD FILES AND THE RPM SYSTEM PRESENTS THE WORD THAT IS IN THE MIDDLE OF THE PICKED FILE ON THE CRT
START
INPUT OPTION OF PICK THE WORD PRESENTED, SEARCH UP OR DOWN IN THE FILE, OR BE DONE WITH THE FILE
KEEP THE WORD?
yes
DO WHAT YOU WANT TO DO WITH THE WORD - BUILD TEXT, SEND IT TO A PRINTER OR A SPEECH SYNTHESIZER OR USE IT TO CONTROL A PROCESS
no
SEARCH UP OR DOWN?
no
DONE
YES
SEARCH UP OR DOWN BY DIVIDING THE CHOSEN UPPER OR LOWER PORTION OF THE FILE IN HALF AND PRESENT THE WORD LOCATED AT THAT POSITION
NO
MAXIMUM DIVISIONS DONE?
YES

Figure 1. BLOCK DIAGRAM OF RPM BINARY SEARCH PROCEDURE

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Note: Patent Pending on the RPM System

"YO VOY, EL VA": A CASE STUDY IN INTEGRATING SPANISH, SYMBOLS, AND A SYNTHETIC SPEECH OUTPUT DEVICE

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ABSTRACT

This case study highlights some of the special problems presented in applying current speech output devices to Spanish-speaking children, and outlines symbol programming strategies that may be used to accomodate differences between Spanish and English. The decision-making process used in intervention with a bilingual, prespelling child is outlined with regard to: (1) communication device selection; and, (2) the programming strategies developed to produce grammatically spoken Spanish from single words stored in a multi-level language display.

INTRODUCTION

Within the United States, there are several children and adults in need of augmentative communication services who are not native or primary speakers of English. Although a few devices designed for other languages are beginning to appear (1,2,3), these may not be appropriate or easily available. Consequently, professionals often need to provide bilingual or non-English speaking individuals with communication access through devices originally intended for the English speaker.

Children and adults whose primary language is Spanish frequently are in need of augmentative services because of developmental or acquired disabilities. Given the paucity of communication devices specifically developed for use by the Spanish speaking community, technology intended for the English speaker may be adapted for use in Spanish in the intervention plan. Minimal information is available, however, on how to accomodate the language differences in the language programming and outputs provided. To date, there has been one reported case of Spanish programming of an English-based device for a bilingual adolescent (4). No published information is currently available on adaptations for the nonspelling, Spanish speaking child using a speech output device. This case report outlines one approach.

SUBJECT

G. is a 6 1/2 year old boy with moderate athetosis resulting from cerebral palsy. Although he is bilingual, Spanish is the primary language spoken in his home, community, and in the classroom. G's primary mode of communication is through augmentative communication techniques. Prior to implementation of an electronic computerized device, G. was communicating through gross gestures, vocalization, eye-pointing, and a two level, direct selection language board of approximately 250 symbols and Spanish sight words which he indicated with a specially designed hand splint. Beginning writing skills were being developed through the use of an electric typewriter.

During re-evaluation, it was decided to augment G's face to face communication with a computerized device that would allow him to communicate through spoken speech (Spanish) and independently access a larger language storage capacity. As appropriate devices in his native language were not available, G. was considered for a communication device designed for the English speaker. The following case report reflects the decision making process that evolved in implementing that recommendation.

COMMUNICATION DEVICE SELECTION

A communication device was sought that could provide G. with increased language storage (500+ words, sentences and phrases), and intelligible Spanish speech output. The language storage desired was a combination of preprogrammed sentences and a large single word corpus that could be combined into novel utterances. Several commercial devices which met these criteria were evaluated.

Of primary importance in the device selection was the intelligibility of the spoken Spanish that could be produced from synthesis systems based on spoken English. Native Spanish speakers programmed and judged the quality of spoken Spanish produced through: (1) altered spelling, using English text to speech algorithms; (2) combining phonemes available in English to approximate

Spanish production; and, (3) the various synthesizers within devices that were under consideration. Phoneme based systems were judged to be more intelligible than altered spelling approaches. In addition, the Voltrax based synthesizer used in the VOIS 135 communication device was judged as superior to other portable synthesizers under consideration that allowed phoneme combination. As a back-up for intelligibility, a visual display was felt to be advantageous if a sufficient number of words could be printed in standard Spanish. Review of available technology indicated that exception tables did not allow for a sufficient number of words/ sentences to appear in this format from a phoneme based approach, and this desirable characteristic was abandoned. The VOIS 135 was selected as the voice output device for this child primarily based on its superior intelligibility for spoken Spanish. Of concern was the relatively small language storage capacity of this device (a four-level, programmable display of 128 items/ level). However, it was felt to be acceptable.

PROGRAMMING ISSUES- SOME ESSENTIAL DIFFERENCES BETWEEN ENGLISH AND SPANISH

Spanish and English have many linguistic differences. These become particularly important in programming communication devices which have symbol/sight word storage and speech output. Some of these differences are briefly illustrated below:

(1) Verb Tenses. In English, verbs generally are conjugated by adding 'ing', 'ed', 's', 'es'. In programming speech output devices, grammatical pronunciation can be accomplished by storing a small repertoire of suffixes which can be added on to any verb as needed (e.g., play+ ing). Or, if a child is not yet able to handle suffixes, a few central forms of a verb can be stored for retrieval (e.g., play, played, playing).

In Spanish, verb endings are not only related to present, past, or future status, but have multiple endings related to the pronoun or subject that it refers to (e.g., I had/yo tuve; you had/yo tuviste; he had/ el tuvieron; we had/nos tuvimos; they had/ellos tuvieron). These multiple endings vary across tenses and verbs. Conjugation of verbs may also effect the way in which the verb root is written and spoken. To illustrate, note the verb root changes that occur in the verb 'play' - juego (I play); jugamos (we play). Consequently, verb programming is much more difficult in Spanish for the prespeller. There are numerous endings that must be stored for regular verbs, as well as multiple pronunciations of the basic verb root if an add-on/ combine approach is used. For a younger child unable to handle the complexity of adding grammatical components, numerous verb forms must be stored for the same verb in order to achieve grammatically correct sentences.

(2) Verb 'to be'. In English, the forms of the verb 'to be' can be represented on a display by a small core of words (eg., is, are, was, were, am). In Spanish, there is a larger number of words for this verb. Each pronoun has a distinct associated "to be" verb form (e.g., I was/ fui; you were/fuiste; he was/fue; we were/fuimos; they were/fueron). In addition, there are both temporary and permanent forms of each 'to be' verb. The form used is related to the referents (e.g.,' I am mad' would use a temporary form). In device programming for the prespeller, these multiple forms need to be stored in order to produce intelligible and grammatical spoken Spanish.

(3) Adjectives. In English, descriptive adjectives are written and pronounced in the same manner whether describing objects, actions, a small boy, or a group (e.g., big). In Spanish, the pronunciation of adjectives alters depending on whether the word being described is feminine or masculine, and singular or plural. Consequently, four different forms of a single adjective are used. To illustrate, 'bonita' can be bonita, bonito, bonitas, bonitos depending on its referent Again, programming for a prespelling child would not use one form, but multiple forms or endings as suffixes.

(4) Infinitive 'to'. In English, the word 'to' can be placed in front of a verb to provide the infinitive form (e.g., to + go). In Spanish, this is a separate verb with its own form (e.g. jugar - to play). Consequently, infinitives need to be stored as separate words.

(5) Imperatives/ object pronouns. In English, several pronoun forms are used as object pronouns (e.g., her, him, me, them). When producing an imperative, these are added to the main verb, as in "tell + her". In Spanish, imperatives have there own verb forms with the object pronoun embedded within the structure of the verb. To illustrate: tell her/ dile; tell them/ diles; tell me/ dime; tell you/dijo. Again, use of this form requires additional verb programming for the prespeller.

STRATEGIES FOR LANGUAGE PROGRAMMING

One level of the device was allocated to preprogrammed sentences and phrases. These presented no special problems as the completed grammatical form was inherent in the utterance. Special programming strategies and new symbols/ sight words were needed within the four level display to allow G. to combine single words into intelligible and grammatical spoken output. These programming and symbol needs were not evident in G's use of a language board as partners generally expanded symbol combinations into the appropriate grammatical form for him. Some of the strategies that were used to accomodate to the spoken language needs of this child are outlined below:

As the number of verb forms is extensive in Spanish and the storage capacity of the communication device is limited, decisions needed to be made relative to which forms were necessary for G.'s communication within the year, and how these would be stored and accessed.

It was decided to utilize the level concept to represent the multiple conjugations of a particular verb associated with various pronouns and subjects. For each verb selected, the verb form associated with 'I' was placed on level 1; 'you' on level 2; he/she on level 3; and 'we' on level 4. G. was reminded of the level/ form through a narrow color coded strip noting the pronoun forms to the left of each main verb symbol. One display square (all four levels) was allegated to the present tenses for a specific verb; a second to the past tenses of that verb. The verb 'to be' was programmed and stored in a similiar manner for both temporary and permanent references. Future verb forms were not specifically programmed in order to conserve space for a wider variety of language items. G. was taught to code future tense through the use of specific word use (e.g., tomorrow, later, Saturday).

The infinitive and imperative forms were not programmed universally for all verbs in G's language display, again to conserve space. As he frequently used these forms with a small corpus of verbs (to play, to go, give me, take me), these were programmed only.

A decision was made not to program four different forms for each adjective. It was felt that intelligibility for these words would not be seriously reduced through use of the female form. A plural 's' square provided the option of adding this sound to the end of plural adjectives.

SUMMARY

This case study illustrates how an English-based communication device with multi-level language storage might be used for a young child needing to communicate through spoken Spanish. It also illustrates the limitations of a 500 item /4 level display type device for novel word utterances in this language. Although this capacity might have been sufficient for this child in English, the grammatical structure in Spanish requires a larger storage to accomodate the multiple grammatical forms needed to produce intelligible novel utterances.

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COMPUTER BASED COMMUNICATION SYSTEMS - THE FUTURE

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ABSTRACT

The short time scale and very rapid evolution of computer based communication systems for the speech impaired has had its effects on research and development. Although great strides have been made in this field, therapists and users have been increasingly concerned that the systems which are available are not being used as frequently or to such an extent as was hoped. There are clearly inadequacies both in the facilities offered and with the methods of training provided which need to be tackled by the research community.

EARLY ELECTRONIC COMMUNICATION SYSTEMS

Electronics communication systems for the speech impaired have only been available for a relatively few years. The early devices were based on special purpose electronic equipment but many had a surprising amount of versatility. Later devices have taken advantage of the availability of low cost personal computers which provided designers with much greater power and data storage for less and less money. Most of the computer based devices have used Apple II computers or (in the U.K.) BBC machines although, particularly for the severly physically disabled, specially built equipment has continued to have an important place. The use of special equipment copes with the problems of people who cannot operate normal computer keyboards, and also can be manufactured in a form that is more easily portable and convenient to use than a standard microcomputer.

In general research work has addressed four main issues:

Access for those who cannot use a standard keyboard

Prediction

Phrase storage mechanism

Systems which cope with language dysfunction

MORE POWERFUL COMPUTERS

The more powerful computers which are appearing on the market are giving designers scope to produce much more complex systems and the introduction of inexpensive "lap-portable" computers will go some way to solving the portability problem. The IBM supported research project at the Hugh MacMillan Centre in Toronto is also investigating methods of providing access to standard computers systems by the physically disabled.

There would seem to be no impediment to the further development of communication systems either on the basis of availability of computer power or cost, and we should expect great strides to be made in the immediate future. The work of Kraat and others (1), however, has shown some warning signs from the clincal perspective. Their studies have shown that clients actually use communication aids and the facilities of them much less frequently than the designers hoped. It appears that the characteristics of technology may be outstripping the demand for such facilities.

Thus, although there is clearly room for more development effort on various types of systems which already exist, it is important for the research perspectives to be analysed so that maximum advantage can be taken of the next generation of portable computers which are becoming available. The real problems to be addressed are not inadequacies in our engineering or a lack of computer power, but they are due to insufficient understanding of the needs and characteristics of potential users. This is an important but complex area and it is vital that teams working in this area should have an interdisciplinary structure and a research orientation.

SOME RESEARCH QUESTIONS

Research questions which need to be asked include:

What messages should communication systems be designed to convey?

Although the more flexible systems allow clients to develop their own messages, this should not be used as an excuse for the designer to abdicate his responsiblility - the medium has some bearing on the message and the types of messages required should be considered by the designer. (As a trivial example, it is inefficient for communication systems to be filled with messages which users can more effectively communicate by facial grimaces - but this may vary from client to client). Designers should investigate clear guidelines as to what messages it is appropriate to have on any system.

What is the most appropriate way to access these messages?

Although technically it is very simple to provide storage for a thousand or even ten thousand phrases, it is a much more difficult task for a user to remember which phrases are stored and how to access them. Multiple menues are one potential solution (2) but these need careful organisation. Baker (3) has also developed a novel access system based on pictogrammes which is designed to reduce the memory load for large phrase storage systems. Other mechanisms for accessing stored phrases need to be investigated.

How can we improve the speed at which words and messages can be accessed?

Prediction is one way but it is important not only that the prediction should make an improvement which is seen to be significant by the user as well as the designer, but that the system should not confuse the user or seem to overly constrain what messages he can give. (An international initiative is investigating prediction as a mechanism for improving the speed at which communication systems can be used (4) and will be reporting at this conference.)

How can we improve the convenience of the system?

Clearly portability and miniaturization are vital and this will follow trends in standard computers. Other aspects which need to be considered, however, include simple questions such as the ease of use whilst standing up - is the display pointing at the person for whom it is intended? - can the volume of the speech synthesizer be adjusted to be appropriate to the ambient noise level? Other more complex issues also arise in terms of optimising the human-machine interface, particularly in the case of severe disability. Tackling these problems needs the skills of occupational and physiotherapists as well as psychologists and eningeers.

A consideration of the problems of training?

In extreme cases communication systems are delivered to users with little more than simple instruction manuals designed to show the user how to turn them on. It is becoming increasingly apparent, however, that all users need to be trained not only to use the device but also how to converse with it, what are the appropriate social rules governing conversations, etc. Designers need to take this into account when producing their instruction manuals if nothing else. A more radical step, however, would include considerations of whether a training program can be built into a system, so that it can act as a training aid as well as a communication aid.

Developing systems which cope with language dysfunction.

The Bliss symbol system has been found to be very successful for users with language dysfunction, but has the disadvantage that it is an entirely different language system to spoken languages. It would be valuable if written-language based systems provided help for those with some language dysfunction.

RESEARCH STRATEGY

There are a number of research strategies which can be adopted in this field, and each have advantages and disadvantages. The research strategy which has been adopted by the Microcomputer Centre at Dundee University is that of an academic institution which is technologically based, but whose staff includes trained occupational and speech therapists as well as psychologists and social workers. Close links have been formed with clinical environments and engineers spend time in clinical work. There is, however, no formal service commitment at all. This freedom encourages a more generalisable approach to problems and offers some protection to research workers from demands which are inappropriate to their research. The balance between maintaining vital clinical contacts and being overwhelmed by day-to-day problems is a very delicate one!

CONCLUSIONS

There is no doubt that tremendous strides have been made in the development of electronic communication systems over the past twenty-five years. Progress in the technology shows little signs of slowing down. Our ability to take advantage of it, however, is restricted by our lack of understanding of what is wanted by the users, and the difficulties in training people to use our currently available systems. Tackling these two related problems should be a high priority in the research community. There has been a tendency to look at these problems from the perspective of the clinician and the engineer as separate exercises - if we are to take the greatest advantage of the more powerful computers which are becoming available, it is important to draw together these two perspectives.

The organisation of the Microcomputer Centre at Dundee University provides one possible model for work in this area, and some of the work of the group is presented in other contributions to the conference (5-7). It is hoped that the integration of the various themes of their research and their close contacts with other groups working in the field will provide a catalyst for innovative ideas in the provision of communication systems for the disabled.

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COGNITIVE ABILITIES IMPLICATED IN THE USE OF COMMUNICATION AIDS

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ABSTRACT

Three tests were developed which were intended to assess levels of language and cognitive abilities considered relevant to successful communication device operation. The tests address spelling, verbal associative learning and learning of spatial location. Data from 10 able-bodied and 22 neuromotorically disabled people was used to deal with issues of test construction.

Scores obtained by device users and people who did not use communication aids because of inadequate spelling skills were reviewed in order to set tentative minimum cognitive operational requirements for operation of classes of communication devices. These were implemented in the Tufts-MIT Prescription Guide to recommend exclusion of devices from consideration if a client's test scores indicated that the devices imposed too great a cognitive demand.

INTRODUCTION

Three tests were developed in order to assess cognitive abilities thought to be involved in the operation of communication aids. All may be taken by clients with no functional speech or augmentative communication technique, so long as there is some reliable means of pointing indication, including eye gaze direction, and four directions of gaze can be distinguished. These tests constitute the cognitive assessment component of the Tufts-MIT Prescription Guide (Goodenough-Trepagnier, et al., 1987).

SUBJECTS

Subjects in this study included 10 able-bodied people with a mean age of 34.5, of which 5 were women; and 22 people, 5 of them women, with a mean age of 35.4, whose neuromotor involvement caused communication difficulties. Etiologies included traumatic brain injury (7 cases), cerebral palsy (5), brainstem stroke (2), amyotrophic lateral sclerosis, cerebral hematoma, cerebrovascular accident, Friedreich's ataxia, anoxic brain injury and Joseph's disease (1 case each).

MATERIALS

The three tests include functional spelling, verbal associative learning (the Code Learning test) and learning of spatial location (the Location Learning test).

Functional Spelling. The rationale for including a test of spelling is of course the vital importance of having access to an alphabet as one or even the only language component of a communication aid. A spelling test was accordingly developed using words primarily drawn from a word list compiled from the communicative output of several adult users of alphabet-based communication devices (Beukelman, 1983). When able-bodied control subjects failed to produce errors on these words, which were mostly at fourth-grade level and below, additional items were included from frequency lists derived from spoken English text (Howes, 1966; Dahl, 1979). A list of 63 words was developed and arranged in order of increasing difficulty based on the errors produced by the 10 control subjects.

The test materials for administering the functional spelling test include a transparent plastic sheet divided into four quadrants, with approximately one-quarter of the letters of the alphabet displayed in each quadrant. When the testee indicates the quadrant containing the correct letter, a correct letter selection is scored. For consistency, verbal identification of an incorrect letter which happens to be in the same quadrant as the correct letter is also scored as correct. When possible, the incorrect spelling is transcribed.

Code Learning. The relevance of verbal associative learning ability to successful communication aid operation is not as obvious as the importance of spelling skills. However it can be argued that some verbal learning is involved in becoming familiar with any device, e.g., learning what words are included in the menu, what functions are signified by the labels on control keys. This ability is particularly important in learning to use devices which have a smaller number of keys than menu items, requiring the user to learn a key-sequence or level-selection in order to access each menu item. The Code Learning test therefore requires learning to associate digits with words.

The test consists of three tasks: the simplest level entails learning a single digit associate to each of three words; the next requires learning a two-digit code for each of five words; and the third requires a two-digit code for each of seven words. Members of each list of word-digit pairs is presented, one at a time, followed by presentation of each of the words without its number associate.

The testee indicates the digit or digits on a sheet divided into numbered quadrants. Feedback is provided after each response by again displaying the word-digit pair. Five trials are presented for each task, unless criterion (all items correctly recalled) is reached sooner. If criterion is not reached by the fifth trial of a task, the test ends.

Location Learning. Fluent operation of a communication aid requires overlearning where menu items are located on the device's menu display. For motor patterns to become automatic, the user needs to learn and remember, with minimal need for visual prompting, where the hand, headstick, etc. is to go for each selection. A test was therefore developed which was intended to reflect the client's ability to learn and recall where, on a stimulus panel, letters were located.

The response sheet for Location Learning is the same used in Code Learning: a clear plastic sheet divided into numbered quadrants. Ten stimulus sheets are presented, each having from 4 to 20 letters divided among the quadrants. After each stimulus is presented for about 5 seconds, it is removed and the testee is then asked to indicate the location of each of four letters selected from the stimulus sheet.

RESULTS

Split-half Reliability. Split-half reliability was computed for Spelling and for Location Learning, at .987 and .825, respectively, using data from all subjects. The number of items in the Code Learning test was judged too small to compute a meaningful split-half reliability statistic.

Correlation with Standardized Tests. All subjects also took three standard tests of cognitive ability which lend themselves to non-verbal, minimally motorically demanding administration: the Raven matrices (Raven, 1960), the revised PPVT (Dunn & Dunn, 1981) and the Quick Test (Ammons & Ammons, 1962). Scores obtained on the three new tests correlated significantly ($p < .005$) with all three standardized tests. The highest correlations were obtained for the Location and Code tests with the Raven matrices (.849 and .810, respectively). This may reflect the fact that performance on each of these learning tasks is enhanced by the subject's elaborating strategies to reduce the memory load. This ability to develop strategies in response to a task-specific challenge is probably related to the problem-solving abilities which the Raven is designed to assess. For example, one subject indicated that he learned the letters for only 3 of the 4 quadrants in the Location test. He was thus able to ascribed unfamiliar letters to the fourth quadrant. Inter-item Redundancy. Inter-item redundancy was computed using the scores obtained by participants with communication deficits only. Code and Location, both of which involve associative learning of some type, were found to correlate significantly with each other ($r = .713$, $p < .005$). Location obtained a lower, but still significant, correlation with Spelling ($r = .534$, $p < .01$). Code and Spelling were not significantly correlated, a finding which is in part due to the largest etiological subset of the subjects in this study, people with traumatic brain injury. While spelling, barring a central language processing deficit (aphasia) or a specific developmental deficit, is usually preserved, ability to learn and remember new material is often selectively impaired in people who have sustained a traumatic brain injury.

Floor and Ceiling Effects. A concern in the development of these tests was to avoid ceiling and floor effects for both able-bodied and disabled subjects. While the population studied did not have severe linguistic or cognitive deficits, it was desirable to include people with some cognitive involvement, so long as this was not severe enough to preclude alphabet-based device operation, because the applicability and usefulness of these tests would otherwise be extremely limited.

Only one control subject obtained a perfect score, on the Code Learning test. One standard deviation above the mean was less than the maximum possible score in the case of all three tests.

Patients who were rated by clinicians familiar with them as not possessing functional spelling skills were not included in computation of the distribution of scores. For the "functionally adequate" spellers, the mean score was 35.7 / 63, with a standard deviation of 10.76. For the Code and Location tests, however, mean minus one standard deviation included chance performance.

Because of the chance scores obtained by some participants in the Code and Location tests, scores were extracted from the easier sub-tasks for computing "minimum cognitive operational requirements", for use in the device exclusion logic embodied in the Prescription Guide. The first task of the Code test (set of three stimuli, each consisting of one word and one digit), and the first four tasks of the Location test (two panels with one letter per quadrant, two with two letters per quadrant) were used. On these items, the mean minus one SD was in the range of above-chance performance.

IMPLEMENTATION OF COGNITIVE TESTS IN THE PRESCRIPTION GUIDE

Test scores coupled with both informal and systematic observation of functional communication device use by participants in this study were used to set minimum cognitive operational requirements for use in the Tufts-MIT Prescription Guide. These scores are consulted by the procedure in order to determine whether the client meets the minimum cognitive operational requirements for each device. A device for which the client does not meet the minimum cognitive operational requirements is excluded from consideration for that client, and a match score (the Benefit score) is not computed for it.

To set these minimum requirements, the following procedure was used: the lowest score obtained by a functional user of a communication device was taken as a demonstration that the minimum requirement for that ability was lower still. Scores obtained on the Spelling test by communicatively impaired people who were not using alphabet-based communication aids because of their spelling difficulties (as reported by their clinicians) provided a de facto minimum - the requirement would need to be at least higher than scores obtained by 'non-spellers'.

The minimum cognitive operational requirements are conservative, that is, they are set low so as not to exclude devices which might be beneficial to the client. Furthermore, they are set for classes of devices (e.g., devices having a menu greater than N, or having a code-learning burden greater than M), rather than on a device-by-device basis. Both of these features are necessitated by the small data base, in terms of patients and devices, from which they are derived.

Scores received on the three tests in the course of assessment using the Tufts-MIT Prescription Guide are recorded by the clinician on a response record form and entered when prompted in the course of running the system.

The clinician has the option of overriding the system's proposed exclusion of any device. This override might be invoked, for example, if the client's Spelling score is below a minimum requirement, but the clinician has been able to transcribe the errors and finds that some of them maintain the words' interpretability, for practical purposes. If the clinician indicates that the exclusion should be overridden, that device's file will be treated by the procedure and match scores will be computed.

Addition of new clients' results to the data base, currently going on, will allow refinement of minimum operation requirements so that they eventually offer more useful guidance in the prescription process. Work is beginning on development of cognitive assessment tasks to be used with younger and more cognitively impaired clients.

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MULTI-CHARACTER KEY TEXT ENTRY USING COMPUTER DISAMBIGUATION

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ABSTRACT

One approach to increasing the text entry rate of disabled users is to reduce the number of keys on the keyboard. The use of multi-character keys represents one technique to achieve this goal. The resulting ambiguity in the text that is generated must be sufficiently resolved if this technique is to prove viable.

This paper describes a method for disambiguating the text produced by a multi-character keyboard. First, the assignment of character groupings to keys is chosen, using a computer optimization algorithm, to minimize the inherent ambiguity in the text that is produced. A second computer algorithm, utilizing both a dictionary of common words and language trigram statistics resolves as much of the remaining ambiguity as possible. Initial tests with this technique indicate that it holds promise for a workable system.

INTRODUCTION

The standard QWERTY keyboard is poorly designed for users whose motor impairments restrict them to one finger key selection or an equivalent. Research has shown that the transition time from one selection to the next increases as the distance travelled increases or as the key size decreases [1]. This indicates text entry rates can be improved if we can either decrease the keyboard size or increase the key size without a compensating change in the other parameter. Reducing the number of keys on the keyboard is required. One traditional approach to this has been the use of coding. However, this has two drawbacks. First, an increased mental load results from the need to learn and remember codes. Second, since the codes for some characters requires more than one keystroke, an increased average number of keystrokes per character occurs, thus tending to reduce the text entry rate [2].

In this paper we consider an alternative technique involving assigning multiple characters to each key. This reduces the number of keys without requiring the user to learn codes and without necessarily increasing the number of required keystrokes. It requires, however, a method for determining the correct, that is the desired, character sequence corresponding to the keystroke sequence. This resolution of ambiguity, or disambiguation, is achieved through two computer procedures. One involves a keyboard design with the goal of minimizing the ambiguity inherent in a keystroke sequence. The other is done as the text is produced, and is the actual disambiguation process.

MINIMIZATION OF INHERENT AMBIGUITY

The problem of disambiguation involves determining which of the possible character sequences is correctly implied by a keystroke sequence. Clearly, if only one of the possible character sequences has a non-zero probability of occurring the ambiguity is resolved; in this case there is no inherent ambiguity. By contrast, if all possible sequences have an equal probability of occurring maximum inherent ambiguity results. In general, the amount of inherent ambiguity will lie somewhere in between, that is, some sequences will be more probable than others.

The design problem, therefore, is to assign characters to keys in such a way as to minimize the inherent ambiguity in the resulting sequences. This depends on the length of the sequences we choose to consider. The following theory is for sequences of two characters, digrams, but can be readily extended to longer sequences.

Consider a keyboard containing K keys with up to N characters per key. We then define

$p(i,j)$ - digram frequency of i-th character followed by j-th character;

$f(s,t)$ - frequency of s-th key followed by the t-th key;

$c(s)$ - set of characters assigned to s-th key.

Then

$$f(s,t) = \Sigma\Sigma\, p(i,j) \qquad (1)$$

where the summations are over the appropriate sets of characters. We also define

$$g(s,t) = [\Sigma\Sigma\, p^2(i,j)]^{1/2} \qquad (2)$$

and the inherent ambiguity of the keystroke sequence s, t is given by

$$A(s,t) = k[1 - g(s,t)/f(s,t)]. \qquad (3)$$

If only one character sequence ever occurs then

$$f(s,t) = g(s,t) \qquad (4)$$

and $A(s,t) = 0$. If all N x N character sequences are equally likely inherent ambiguity is maximized and equal to

$$A(s,t) = k[1 - 1/N]. \qquad (5)$$

We can normalize this maximum to 1 by letting

$$A(s,t) = [1 - g(s,t)/f(s,t)]/[1 - 1/N]. (6)$$

For an entire keyboard the inherent ambiguity is given by

$$A = \sum_{s}\sum_{t} f(s,t)A(s,t); \qquad (7)$$

the problem is to choose the assignment of sets of characters to keys so as to minimize A.

One approach to this optimum assignment problem utilizes an evolutionary adaptive algorithm [3,4]. The application of this technique to the related problem of alternative character arrangements on a keyboard has been described by Levine [5] and Levine et. al. [6]. The algorithm begins by randomly creating a number of feasible designs. A feasible design is one that meets constraints such as number of keys and maximum number of characters per key. This constitutes the zeroth generation of designs. Each of these are then evaluated using the measure in equation [7] and, based on some reproductive rule, the better designs are selected and allowed to reproduce. The new generation of designs differ from their parents due to random mutations, essentially involving switching of pairs of characters. This pattern of selection and mutation is continued until the performance level of the best design evaluated is judged satisfactory or further significant improvement seems unlikely.

DISAMBIGUATION OF TEXT

Minneman [7] has developed an algorithm with the goal of extracting readable text from Touch - Tone® keystroke sequences. The same algorithm can be utilized with keyboards produced by the evolutionary adaptive algorithm. In this algorithm one of the keys is designated as the space character and serves as a word delimiter. The sequence of keystrokes between delimiters is assumed to represent an English word. Two approaches are used in disambiguating the keystroke sequence. One uses a dictionary of frequently occurring words and determines if any match up with the sequence. The second uses an analysis of trigram (three consecutive characters) frequencies and selects those character sequences with the highest probabilities of occurrence.

Several problems can occur. More than one dictionary word may match the keystroke sequence; this is referred to as a collision. No English words may be deciphered. A collision may occur between a word from the dictionary and one resulting from trigram analysis. Finally, all the words deciphered may be incorrect.

Other approaches to disambiguation exist. The problem of constructing Chinese characters using a keyboard has been explored using a disambiguation technique utilizing an optimization technique known as a Genetic Algorithm [4]. Genetic Algorithms simulate not only mutation but other genetic operators, recombination and inversion, as well. More closely related to the present research, Foulds [8] has considered the use of quadgram frequencies and no dictionary as a disambiguation technique.

SOME RESULTS

To determine the level of improvement obtainable by using better assignment of sets of characters to keys a keyboard with ten keys was designed and compared with the Touch - Tone® design. Each keyboard was used to generate a 399 word sample, and disambiguation was based on trigram analysis alone. The three top choices for correct words were displayed for each word. The Touch - Tone® produced 222 correct matches, 64 first choices, 106 second choices and 52 third choices. The optimized design, which contained up to four characters per key, produced 292 correct matches, 185 first choices, 81 second choices and 26 third choices.

An optimized keyboard restricted to three characters per key and ten keys produces an ambiguity performance measure of approximately A = .485. Allowing four characters per key, such as in the board tested above, decreases this to A = .456. Allowing as many as eight characters per key further reduces this to A = .423. The relationship between the measure A and actual correct matches still requires further investigation, but indicates the possibilities for significant improvement.

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MULTI-CHARACTER KEY

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QUANTIFICATION OF DEVICE EVALUATION

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ABSTRACT

The Tufts-MIT Prescription Guide is a computer-based system which has been developed to assist the clinician in prescribing communication devices for adult motor-disabled nonvocal clients. It utilizes data gathered in communication-device-independent assessments to calculate scores predictive of the communicative "Benefit" the client can expect from each candidate device. The numerical device data necessary for this calculation is gathered in the laboratory according to an evaluation protocol which calls for 300 measurements, observations, and subjective judgements. That protocol has now been applied to several commercial electronic aids. The results suggest some generalizations about Needs not well served by existing devices and allow interpretation in terms of the subjective tradeoffs which determin a user's overall satisfaction with a device.

INTRODUCTION

The large and growing number of communication devices which can be used by people with neuromotor deficits affecting their speech, and the multidimensional problem of selecting the device which will be best suited to the needs and abilities of a given individual, provided the motivation for the development of the Tufts-MIT Prescription Guide. In the hands of a clinician who need not have expertise in augmentative communication or computers, it can make predictions of the relative communicative benefit a client can expect from each of a number of different devices. Pilot studies of the validity of these predictions have had positive results [1].

The Prescription Guide operates on the basis of the principle of abstract, predictive assessment. It is abstract in that the client assessment is carried out without communication devices using specially designed tasks which simulate the demands of expert device operation. The comparison of motor abilities with device parameters uses a mathemetical model of client motor ability derived from assessment data and a file of device-specific information to derive an estimate of communication rate for each device [2].

The client's living circumstances, constraints, preferences, and expectations are sampled by means of a questionnaire and transformed by a knowledge-based system into a profile of desirable device characteristics for comparison with device feature files. This comparison generates the "Benefit Score", B [3].

The basis for determination of B for a candidate device is the calculation of three parallel profiles which represent the Needs of the client, their Importance Weights, and the Needs Met by the device. For each Need established to be present for the client, the Benefit Score is incremented by an amount equal to the Importance Weight calculated for that item for the client. The items in the Needs and Needs Met profiles are intermediate between the human-functional language in which the client and clinician can legitimately describe the client's circumstances, and the quantitative technological specificity with which device features and functions must be defined.

Lotus 123 was used as the substrate for this knowledge-based system. It was chosen because of the high liklihood of its availability to users of the Guide, the richness of the functions available for composing equations, the convenient tabular format it provides, and the convenience of the utility functions it provides during development of a system like this. Continued development of the Guide will probably include replacement of Lotus with an expert system shell and/or a a language such as Prolog meant for knowledge coding.

The device Feature data required for derivation of the Needs Met profiles is stored for access by the Guide software (written in C) in a Lotus worksheet called DEVICES. This data is collected using a detailed technical evaluation of communication devices developed as part of the Prescription Guide. Steps executed automatically by Lotus command "macros" apply formulas stored in another spreadsheet called RIGHT to derive the elements (1's and 0's) of the Needs Met profile by operating on the Feature data. This article summarizes major features of the device evaluation protocol and calls attention to some results of its application to a set of communication devices.

DEVICE EVALUATION PROTOCOL

Evaluation of a device for the purpose of preparing a file which will be consulted by the Prescription Guide is performed according to a specific ordered checklist of assessments. This evaluation is meant to be performed in the laboratory on all commercially available devices with the results stored on a diskette file for inclusion in the Guide software. Steps taken for commercialization of the Guide will included provision for ongoing evaluation of new communication devices and new variants of existing devices as they come on the market.

The Evaluation results in the determination of approximately 300 numbers according to an explicit and self-contained protocol. These Features include three types of entries:
- objective measurements or counts of physical parameters of the device;
- "1" or "0" entries signifying the presence or absence, respectively, of a discrete feature or property;
- and numerical representations of subjective judgements.

The following are representative samples of device Features of each type.

Objective measurements:
battery life, i.e. time between charges or replacements;
printed circuit board thickness;
number of ways to connect cables between components;
maximum and minimum dwell times for keyboard actuation;
number of words available in the language menu;
luminance of optoelectronic output;
smallest distinguishing feature of hard copy characters;
maximum volume of speech output.

1/0 entries:
the printed circuit board is epoxy-fiberglas (or not);
the company provides a service network;
the device is non-electronic;
the device is joystick operable;
the printed output has a continuous character font;
the speech synthesizer offers spelled speech.

Subjective ratings:
cognitive difficulty of changing the battery, three levels;
dexterity required to change the paper, four levels;
clarity of the manual on the subject of user programming;
adequacy of the case fasteners, five levels;
clarity of the connector labels, four levels;
resemblance to a toy, yes or no.

Not all items apply to all devices. No entry can be made, for example, for "maximum scan rate" for a device which is not a scanner. The convention applied consistently is that no entries are made for Features which don't apply. Although Lotus formulas will read a blank as 0, the equations in the RIGHT spreadsheet were written to establish that a Feature does apply before reading its value.

RESULTS OF APPLYING THE EVALUATION

During the last two years, the Evaluation has been applied to 29 devices, most of them loaned to the Biomechanics and Human Rehabilitation Laboratory in the Mechanical Engineering Department at MIT for this purpose. (Manufacturers were uniformly cooperative in providing devices for this study.) This device testing was essential for preparation of the device data base for the edition of the Guide submitted to NINCDS, for evaluating the generality and correctness of the Needs Met equations, and for reality-testing the device evaluation protocol itself. Because the Evaluation has evolved during this same period, only 15 devices have been evaluated according to its current version. These include 10 direct selection devices, 4 scanners, and 1 encoded system. The remainder of the device files are in the process of being updated.

While the raw Evaluation data cannot be meaningfully summarized, the Needs Met profiles for the 15 devices can be interpreted in functional terms. Results may be summarized as follows.
- Percentage of all Needs Met by each device : mean=33, min=25, max=43.
- Percentage of all Needs Met by all devices = 4.
- Percentage of all Needs not Met by any device = 19.
- For 10 subjects in this study who are experienced device users:
  percentage of their Needs which are Met by their commercial device -- mean=38, min=23, max=46.
  BREL, i.e. Benefit score their device achieves expressed as a percentage of the score which would be achieved by a device Meeting all their Needs -- mean=47, min=29, max=59.

In addition to these numerical results, some other suggestive observations could be made about the Guide output for these same subjects':
- Virtually all of these subjects use both a commercial electronic device and a home made non-electronic language board. Comparison of BREL scores within subject revealed that the language boards score higher than the electronic devices as often as they score lower.
- Two subjects were regular users of two electronic devices. In one case, BREL differed by 4 points (51 vs. 55) and in the other it differed by 15 points (44 vs. 59). In the latter case, the effect of importance weighting in the calculation of the Benefit scores was particularly apparent; the unweighted percentages of his Needs met by the two devices were identical at 43.

DISCUSSION

On average over the device sample being discussed here, about a third of all the device properties defined by the Needs profile are met. Detailed examination of the Needs Met profiles for these devices reflects their diversity; the distribution of 1's and 0's varies considerably among them. This is suggested by the observation presented that only 5% of the

Needs (i.e. 4 of them) are met by all devices.

The observation that 19 percent of the Needs are not met by any device can hypothetically be explained in several ways. The judgements embodied in the equations which conclude that a Need is Met or isn't are, of course, open to question and the process of disputing and revising them is continuous. This involves both modification of logic and adjustment of the thresholds which are necessary to generate the binary Needs Met scores from Feature values many of which can take on a range of values. In addition, the equations may not be adequate representations of the authors' judgements. For these devices, however, several passes *have* been completed of testing the equations' conclusions against the authors' reactions in direct device observation -- and revising where necessary. To the extent that the positive results of the pilot validation trials will be born out by further research, the 19 Needs which are not met by any of these devices reflect an actual gap in the function provided by existing devices.

Examination of the list of Needs never met reveals a few generalizations for which a strong case can be made:

- There is considerable room for improvement in the quality of synthetic speech.
- Convenience of user programmability could also be improved.
- The learning demand and ongoing mental load in use are in no case minimal for user or receiver.
- Flexibility of operating mode and capability of being operated with a variety of interfaces, in particular analog controls, are often lacking.
- Reliability and the ability to survive a wet or dirty environment could also be improved.

It should be noted in this connection that a potential application outside the clinic of the "expert system" which derives the Needs Met profile and calculates Benefit is use as a guide for designers. It should provide a model for testing the effects of design iterations on expected benefit to particular categories of users.

The effect of weighting the Needs present and Met according to their individual importance to the client is reflected not only in the large difference in the two BREL scores noted above but also in the considerably higher values achieved by BREL (mean 47) than by unweighted percentages of Need Met (mean 38).

Some appreciation of the observation that it is not uncommon for simple language boards to outscore electronic aids can be gained from examination of the subscores which add up to B (and which are available for examination by the clinician as an output of the Prescription Guide). Each of these subscores combines B increments related to a particular aspect of function, e.g. portability, or cognitive demand. A particular example in which a word board and a direct selection electronic device achieve about the same value of BREL shows the board winning many points for portability and reliability which the electonic aid comes out ahead with respect to output. It is important to note that few general rules can be stated for superiority outside the context of the particular client's needs.

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COMPUTER AIDED CONSTRUCTION OF NONVERBAL COMMUNICATION BOARDS

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ABSTRACT

Graphic oriented computers can be used to aid in construction of communication boards or electronic communicator overlays. Images suitable for a particular user can be selected from collections of images produced commercially, scanned from existing images or created using a graphics program. Use of this system will speed communication board construction and reduce reluctance to change the board with changing user needs.

INTRODUCTION

A speech/language pathologist trying to establish a communication system for a nonvocal person is limited to few choices. These include sign language, writing, typing, or some variation of communication boards, possibly electronic. For the physically handicapped, choices may be limited to communication boards.

POSSIBLE SOLUTIONS

Presently many language boards and electronic communicator overlays are constructed by pasting pictures on a stiff backing or photocopying appropiate pictures from card sets such as Talking Pictures developed for speech pathologists. The completed overlay can then be laminated for durability.

Unless noted, for simplicity the remainder of this paper will refer to both overlays and communication boards as communication boards.

Construction of these boards and overlays can be a time consuming and tedious process for a speech clinician. This leads to situations where staff thinks twice (or three times) before changing a users vocabulary.

ALTERNATE SOLUTION

Fortunately, commercially available computer hardware and software can speed development of these communication boards. A readily available system could consist of an Apple Macintosh computer, printer, external disk drive, image scanner, graphics software, and collections of graphic art discs.

The Macintosh computer has been available in several configurations since its introduction, and is presently offered as an Enhanced Macintosh with 512K of memory or the Macintosh Plus with 1024K of memory. As of this writing, Apple Computer has announced two additional models, the Macintosh SE, an improved Macintosh Plus, and the Macintosh II, with color display capability and other improvements. Because graphic manipulation is a memory intensive operation, compilation of the images used in an overlay will proceed faster if the computer has more memory (third party vendors provide upgrades to 4096K for either machine). Storage of the graphic images can be a problem due to their data size. As a minimum, two floppy disk drives are required. Even better are hard disc drives which can hold from 10MB (1 MB = 1000KB) to 80 MB. Besides reducing disk swapping, hard disks access their data faster, speeding your work. In the future, optical data disks with their enormous capacity might be used for image storage.

There are three choices for printers, the Imagewriter II for normal width paper which can produce color drawings, the wide carriage Imagewriter which can accommodate 15" wide paper, and a Laser printer for fine detail printing.

As a first step, general drawings must be collected appropriate for the communication board communicator user population. This can be done in several ways The simplest would be collections of images on disks available through numerous commercial or public domain sources, as illustrated in Figure (1).

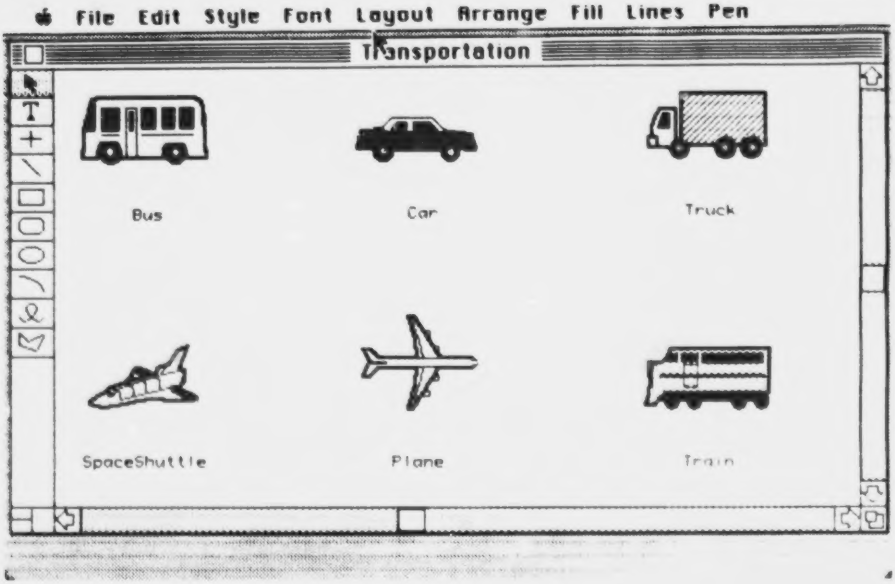

Figure 1, Clip Art Sample

An image scanner such as Thunderscan (1) can be used to read images into the computer.

A filing program such as Picturebase (2) can be used to organize and group pictures for easy retrieval.

Next images suitable for the particular user must be chosen and any necessary custom drawings created using a graphics program.

Layout grids for pointing boards can be constructed using a graphics program. As shown in Figure 2, overlays for electronic aids can be produced by scanning a blank overlay. This allows the pathologist to place pictures around cutouts for lights and sensors.

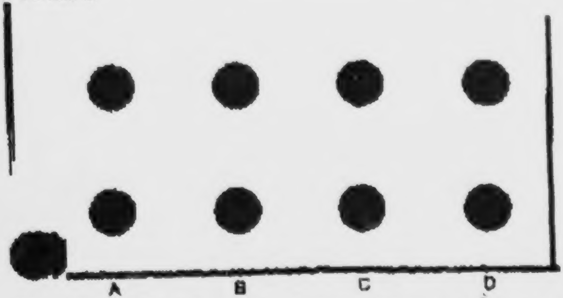

Figure 2, Partial Scan of a Prentke-Romich Minspeak Overlay.

Finally layout of the individual pictures within the board must be completed with regard to logical groupings, frequency of use and selection method. Pictures can be resized larger than a single grid square.

Figure 3 shows the MacDraw program (3) being used to transfer images from the left document onto the image of a 1" X 1" grid

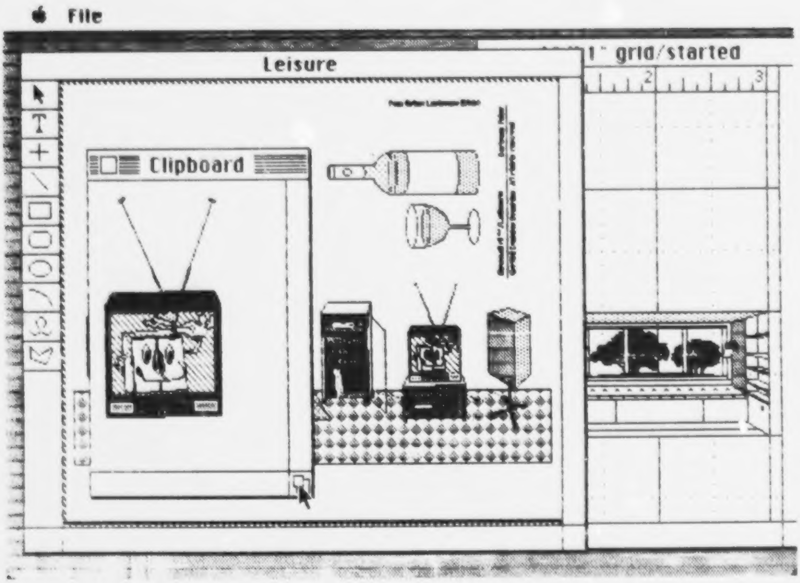

Figure 3, MacDraw used to transfer images.

If a single hole punch is adapted with a longer throat, holes in an electronic communicator overlay can be punched for visual indicators or sensors.

FUTURE PLANS

If demand warrants, companies or other organizations might market compilations of images suitable for overlay use on computer disks.

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Special Interest Group 4

Prosthetics and Orthotics

Chair: T. Walley Williams, III

WAYS TO CONTROL MULTIFUNCTION MYOELECTRIC PROSTHESES

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ABSTRACT

Several electric elbows now are proportionally controlled by myoelectric signals from two muscles. While early elbows were fitted with split hooks, electric hands and Greifers are routinely used today. These can be controlled independently with switches or positional servo transducers or the myoelectric control can be shifted from the elbow to the hand with one of several selection schemes. This paper describes the currently available switch and servo electric control schemes and several methods for selecting which function is to be controlled myoelectrically.

INTRODUCTION

In recent years manufacturers have made available a number of electric prosthetic components. There are several elbows and hands and even a wrist rotator. In addition, Jacobsen and his colleagues at the University of Utah have fit subjects with a humeral rotator on an experimental basis. These new devices have brought with them a considerable challenge. The prosthesis designer must provide for some way to control each function. This paper will explore how various manufacturers and prosthetists in the field have handled the control problem and will discuss the patient acceptance of a new function selection scheme being used with the Liberty Mutual Boston Elbow.

INDEPENDENT OPERATION OF TWO FUNCTIONS

The original Boston Arm project was designed to make elbow and hand control independent of each other (1). The remaining biceps and triceps muscles controlled the speed and direction of elbow motion and a conventional harness and cable opened the hook. The Utah Arm has also been operated successfully in this mode. The hook is a functional device which does not hide objects as an artificial hand does. Many amputees do well with an electric elbow and hook, and either the Boston Elbow or the Utah Arm offer complete independence of elbow and hook control.

Cable operated hands have rarely worked for above elbow amputees, but electric hands are often preferred to hooks either because of their appearance or their greater grip strength. A hand can be controlled independently by using myoelectric sites just for the hand and switch control for the elbow. Several patients have been fit this way; the usual control, however, has been a multiposition pull switch. Such a switch requires the use of special harnessing principles discussed below, and this form of control is usually rejected if these principles are not carefully followed. Switch operation precludes the control of prehension speed.

Pull switches to control electric hands

For the last eight years, Boston Elbow wearers have been fit with both electric and hook type terminal devices in about equal numbers. Until 1985 all of the hand or Greifer users operated the terminal device independently using a multiposition switch. The first switches were those designed through a Veteran's Administration program and made available by Fidelity Electronics. More recently most people have gone over to the Otto Bock 9X14 harness mounted switch or to the 9X18 cable pull switch.

How pull switches operate. All switches have a similar mode of operation. They contain two double-pole single-throw microswitches which are sequentially activated by cams. Figure 1 shows the way the 9X14 switch is connected to its 4-wire cable. In practice, all of these switches connect both sides of the hand motor to one side of the battery in the unpulled position. As the switch is pulled, one microswitch shifts state and one side of the motor receives voltage of opposite polarity. Further pulling shifts the second switch. (Both motor leads are now shifted.) Finally, a fully pulled switch shifts the first microswitch back so the motor again sees voltage but in the opposite direction. The states where both sides of the motor are connected to the same battery terminal short the motor and provide dynamic braking. These same switches can be used for other purposes; and Bock uses the 9X14 to send logic signals to its 6V hand with a logic operated bridge circuit. The preferred configuration with a Boston Elbow is to supply 12V to the hand with no bridge circuit.

Location of switches. The ideal arm prosthesis allows the upper arm to go through the full range of motion remaining post trauma. The conventional cable operated prosthesis fails here, because it harnesses humeral abduction and forward flexion to pull the cable. With a switch requiring only a few millimeters travel, these motions need not be impeded. Figure 2 shows how a relatively low attachment point on the humeral socket is used to obtain up to five inches of cable motion conventionally. In Figure 3 on the other hand, the attachment point is raised so that the line of action of the strap and switch passes over the glenohumeral joint. Abduction and forward flexion hardly pull this strap at all, but forward motion of the shoulder does.

Proprioception and switch control. Eight years of clinical experience with pull switches have lead to certain conclusions. First, most of the switches have limited travel, 4-6 mm. This travel is adequate for sensing the three levels of pull only when the switches are activated by chest expansion. If these switches are placed in a traditional nylon web harness, the amputee must use a gradual increase in pull until action occurs to find the first active position. Several years ago Carl Mason of the Veterans' Administration suggested a better arrangement. The typical switch is placed in series with a piece of elastic. With this scheme an amputee might have to pull 15 mm for the first activation position and 30 mm for the second. This is a sufficient distance for the body's proprioceptive apparatus to be useful. The amputee can place his shoulder or other body part in a known position to get a desired result.

Positional servo for independent control

During 1986, Hugh Steeper Ltd. in the United Kingdom began to offer adult size electric hands with positional servo control. A half-inch (13 mm) displacement of a harness mounted transducer makes the hand open fully. Control is proportional to distance, so that a quarter inch displacement will open the hand half way. Experiments are now under way with this servo system and the Boston Elbow. A servo controlled hand permits independent control of the hand and elbow. If the transducer is attached high like the switch in Figure 3, the amputee can move the upper arm through the full range of flexion and abduction and still control the hand with a forward motion of the shoulder. This system is now available from Liberty Mutual for anyone wanting to do an experimental fitting.

Why give up independent control

There are several reasons for giving up independent control. With shoulder disarticulation, forequarter amputation and brachial plexus injury, it may not be possible to harness sufficient body motion to operate a hook. Alternatively, the amputee may want an electric hand as the terminal device and find the multiposition switch a nuisance. Desire for proportional hand control is another reason for giving up independent control.

MULTIFUNCTION SYSTEMS WHERE CONTROL SHIFTS

The first electric prosthesis to shift myoelectric control back and forth between two functions was the Utah Artificial Arm designed by Steve Jacobsen and others at the University of Utah (2) and manufactured by Motion Control, Inc. The simplest Utah Arm uses proportional myoelectric control from two muscle sites. When the unit is turned on, the two muscles control flexion and extension of the elbow. However, if the elbow is parked in one position for a predetermined wait period, an elbow lock automatically engages. Unlocking is initiated by a strong contraction of both control muscles. This system is used with a cable operated hook as the terminal device.

Cocontraction shifts control of Utah Arm

To add proportional hand control to the Utah Arm, the designers created a circuit to shift myoelectric control to the hand whenever the elbow locks. To shift back requires a rapid cocontraction. Where an amputee fails to master the rapid cocontraction, the older unlock circuit is used. The rapid cocontraction avoids inadvertent control shifts.

Cocontraction to shift control of the Boston Elbow

Stephen J. Greelish reported on a Liberty Mutual cocontraction scheme at the 1986 RESNA conference (3). To avoid ambiguity, the Liberty circuit defines a small cocontraction window using both A+B and A-B where A and B are the two myoelectric signals. The circuit is not practical for routine inclusion in a prosthesis, but it is enabling students at the University of New Brunswick under the direction of Professor Robert Scott to study the psychological aspects of a cocontraction system. This system can return control either with another cocontraction or with total relaxation of both control muscles. We need to know whether typical subjects can control these shift procedures and whether they can do so with 100% reliability.

New Liberty Mutual Selection Scheme

Pull switch selects function. More than six patients have now been provided with a Boston Elbow and an Otto Bock hand or Greifer where control function is selected by using a harness mounted pull-switch. In all cases, the output of the proportional myoelectric motor control circuit is connected directly to the hand or Greifer whenever the switch is in its unpulled position. The amputee shifts the output of the control circuit to the elbow by pulling the switch. Forward shoulder motion and chest expansion are two ways to activate the switch. The change of state is almost instantaneous and the amputee is never confused as to which state is active. This is important. We will discuss the ambiguity in other function selection schemes below.

How the system works. The selector is simple and unsophisticated. The switch is usually an Otto Bock 9X14 pull switch, but other switches can be used. The Bock switch has four positions--unpulled and three active positions, but only the fully pulled position is used in the simple selection scheme. Thus the switch can be thought of as having two positions. Switch motion activates a pair of double-pole double-throw relays. One relay directs both motor control output lines either to the elbow motor or to the hand or Greifer. The second relay is required to deactivate the elbow up and down limit switches when the hand is in use. It is important to note that both sides of the motor output must be switched; otherwise, the unused motor circuit remains coupled to the high frequency (20 kHz) pulse width modulation circuit which generates unwanted electrical interference.

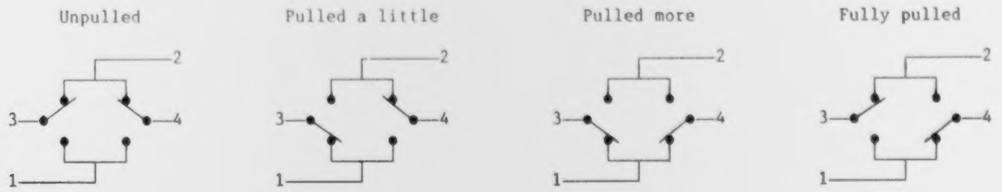


Figure 1. The Otto Bock 9X14 pull switch is connected to the circuit controlled by a 4-wire cable. The total displacement of the pull bar is only 6 mm (.23 inch) when fully pulled.

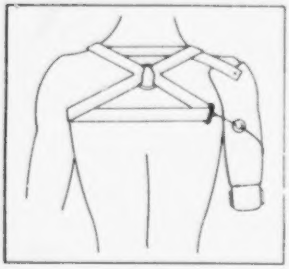
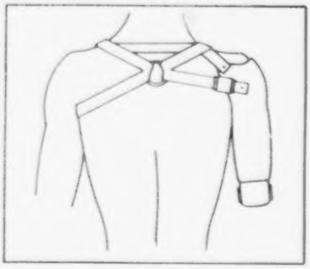


Figure 2. Attachment low on upper arm uses abduction and flexion to operate prosthesis. Up to 5 inches of cable travel can be obtained.

Figure 3. Attachment high on upper arm decouples abduction and flexion. Only forward motion of the shoulder will activate the switch.



The amputee's perception of the system. The user of this selection scheme must maintain switch activation during the entire time that elbow function is desired. While this activity seems extra and superfluous, it is reported to the central nervous system both by the pressure of the activating harness and by positional proprioception. The latter is particularly important because it permits the selection activity to become subconscious like the motions used by skilled automobile drivers. The one function at a time controlled myoelectrically requires more effort because it depends upon visual feedback of positional information.

Adding a third function. It is trivial to add an additional relay to the selection circuit to control one more function. Here hand control remains assigned to the unpulled switch position and elbow control to the fully pulled. The intermediate positions then select operation of the Otto Bock wrist rotator or some other device. This circuit adds both complexity and weight to the prosthesis and has yet to be fit to a patient. Since many patients have used the multiposition switch for hand control, we know ahead of time that switch selection of three functions is doable.

Other selection schemes. David Hawkins and the electronics team at Hugh Steeper, Ltd. in London have worked extensively to adapt the Boston Elbow to some of the special needs of both British and overseas patients. Their switch-switch control scheme is worth mentioning because it may be of use to other workers. The Steeper scheme uses a single Bock 9X14 switch to select direction. For instance, the first pulled position closes the hand and the third opens it. A second simple push or pull switch does the selection. The default or startup function is assigned to the hand. A single, momentary activation of the second switch selects elbow function, and two activations in rapid succession select wrist function. Both wrist and elbow function must be used almost continuously or they revert the control to hand function. There is a slight hesitation in the circuit that reverts control so that the patient can reverse direction if the elbow or wrist overshoots the desired location. Steeper has discussed using this selection scheme with proportional myoelectric control replacing the pull switch. The scheme avoids the need for a continuous pull for activation as in the Liberty selection scheme. It also avoids the ambiguity of most toggle systems, because it reverts to hand control automatically. As one can imagine, the scheme requires considerable electronic board space for implementation.

SUMMARY OF CLINICAL OBSERVATIONS

1. A pull switch moving a mere 5 mm can be made into a switch moving 30 mm by activating the switch with easy-to-stretch elastic.
2. A control strap that passes over the glenohumeral joint will not be activated by abduction or forward flexion of the humerus.
3. Such a control strap can activate a two position or multiposition switch or a positional servo.
4. A properly located and adjusted multiposition switch permits proprioceptive feedback when selecting switch position.
5. Proportional myoelectric control with two muscles is a good way to control speed and direction with visual feedback.
6. A long above-elbow amputee benefits if the prosthesis can operate with the upper arm in any position that can be easily achieved.

CONCLUSIONS

The observations above seem obvious. They are not to most prosthetists. Each of those who have fit the Boston Elbow with the hand-elbow circuit has given it a rave review. Why? The patients ought to be better off with independent control. Perhaps proportional control of the hand is of overwhelming importance to amputee function and that is why they like this system. Also, the switch needs little thought. It is either pulled or not. There are no other positions in use. We need to study the real advantages and disadvantages of these systems so when we design with more functions amputees will be able to use them easily.

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Five New Amplifiers for Detecting Myo- and Bioelectric Signals

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Abstract

A family of five electrode-amplifiers has been developed to address the negative aspects of other biopotential detectors. Two units are designed to detect potentials all the way down to DC, while the other three are optimized for electromyography, electrocardiography, and general research into biopotentials detectable on the skin. Important characteristics are ultra-high input impedance (10^{14} ohms), common mode rejection in excess of 100 dB, protection from static electricity, and immunity to motion artifact. The amplifier package measures only 17.2 x 26.3 x 5 mm with stainless steel electrodes 4 mm dia., 1.3 mm high, and 15 mm center to center. The superiority of the myo-electric version of the unit is illustrated by its ability to detect myoelectric signals well when placed directly in contact with hair on dry skin.

Introduction

Current bioelectric detectors have many problems and are exceedingly delicate. Sometimes, even just holding one in your hand on a dry day can overload it. Consequently, many people who work with them are wont to say "My kingdom for a better biomedical amplifier!"

The electrical signals produced by the human body are subtle and challenge the limits of technology. However, a recent breakthrough in the design of integrated circuits has allowed a parallel advance in the development of five new amplifiers for detecting Myo- and Bioelectric signals. These new amplifiers were designed to serve as a flexible basis for a wide range of bioelectric detection while eliminating many of the limitations of earlier devices. They should have many clinical applications, including advances in prosthetic control, remote cardiac monitoring, and general improvement in the reliability of existing electrocardiography devices.

A Typical Amplifier

The problems involved in acquiring bioelectric signals can be appreciated by considering the operation of a typical amplifier.

In the example, the goal is to amplify an EMG signal to a level of .1 volt root-mean-square (RMS) as might be required in a biofeedback device. The EMG signal we wish to acquire from the skin surface is 10 uV (microvolts) RMS, 10,000 times smaller than our goal. Another signal is also present on the skin surface, an interference signal called common mode. This common mode signal is a result of electromagnetic waves from a multitude of sources, both man-made and natural. In keeping with our real world example, we will define the common mode signal to be 2 volts RMS, or 200,000 times larger than the surface EMG.

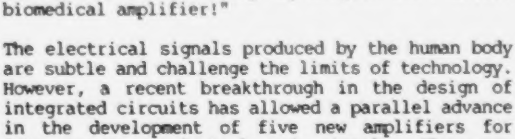

Fig 1

Simple amplification is not the answer, since the common mode would be amplified right along with the EMG. What we need is a method to amplify the EMG and reject the common mode component. A special form of amplifier called instrumentation configuration fulfills this need. Fig. 1 presents the functional diagram of a myoelectric or EMG amplifier based upon the instrumentation configuration.

Basic Operational Theory

The following overview provides the basic operational theory of a conventional EMG amplifier. The object of the discussion is to convey the process by which the EMG signal is amplified and Common Mode rejected. Other parameters, such as input impedance, noise ,and drift characteristics will be discussed in a later section.

The signal input to the amplifier is denoted by the symbols EMG, the myoelectric signal, and both CMs ,the common mode signal. The input stage represented by operational amplifiers A1 and A2 form a differential input - differential output amplifier. It is the function of the input stage to amplify the difference signal, EMG, while passing the signal common to both inputs (common mode) unchanged to its output. In our example, the introduction of reactive elements XRC1, XRC2, and XRC3 form a bypass filter which selectively amplifies those frequencies defined as EMG. In practice, for reasons that will be pointed out later, only modest amplification of the EMG signal is possible in this stage. Assuming a gain of 25, the EMG output of the first stage is 250 uV (microvolts), and common mode is unchanged at 2 V (volts).

The next stage, Operational Amplifier A3, is configured as a differential amplifier with single-ended output. A3 amplifies the EMG signal by a gain factor established by the ratio of the source Rs to feedback Rf resistance. Unlike the input stage where common mode was passed unchanged, it is now subject to attenuation. The level of attenuation or common mode rejection ratio (CMRR) is a function of the quality of the A3 operational amplifier and matching of the source and feedback resistances. Assuming a 250 uV EMG input to the differential stage and a gain of ten, the output will be 2.5 mV (millivolts). To reduce the common mode component to less than 5% of the EMG implies that no more than 250 uV of common mode appears in the output of the differential stage. To achieve this level of CMRR, 8000 to 1 (78 dB), requires very high performance operational amplifiers and precision resistors.

Following the differential stage, a bandpass amplifier with a gain of 40 is used to raise the signal level to our goal of .1 V.

Those familiar with myoelectrics will note that the performance goals for our example myoelectric amplifier were modest. A more typical requisite would be the ability to acquire 1 uV EMG signals with 5 to 6 volts of common mode. While this level of performance is possible with previous technology, the resulting amplifier would have a short service life. Pushing device limits exposes the drift characteristics of the semiconductor process and yields unreliable amplifiers.

Additional Factors

As mentioned earlier, a few factors were ignored in our simplified example and must be accounted for. The first of these factors is the noise performance of the biomedical amplifier. Electrical noise is introduced by the operational amplifier and resistive components that make up the amplifier. The goal of noise reduction is to lower the noise content of the desired signal to insignificant levels. The noise performance of current biomedical amplifier is generally acceptable, but could stand improvement.

Motion artifact is a low frequency signal observed during movement of the electrode with respect to the contact point on the skin. The effect of this artifact is masking of the bioelectric signal and possible saturation of the amplifier. Depending on the application, motion artifact can range from a minor annoyance to total blocking of the bioelectric signal. The artifact is a result of charge displacement as seen by the amplifier. Two factors contribute to the build up of this surface charge. The first is the galvanic couple created between the interface of skin, electrolyte (perspiration) and electrode contact. The second and most prominent contributions are the circulating currents of the amplifier itself. Circulating currents are the product of input bias and various leakage paths between the amplifier virtual ground and supply rails.

Amplifier reliability is a sore point with most users. The fragile nature of the electronics make damage due to electrostatic discharge (ESD) a common occurrence. Because some amplifiers can be damaged by small discharges it is not always apparent what has gone wrong. While some multi-electrode amplifiers include modest ESD protection, the inclusion lowers performance levels.

The remaining factors of power consumption and drift are related. Power consumption of the bioelectric amplifier must be minimized to limit self-heating effects. The devices used in the construction of these amplifiers tend to be heat sensitive, where heat-induced drift may severely degrade their performance. In addition, many of the systems to which the amplifiers are connected rely on batteries where power is limited.

Each improvement in bioelectric amplifiers has come from advances in the process technology of integrated circuits. Fortunately, the need for better interference rejection, higher input impedance, and lower power consumption in the biomedical amplifier is common to all electronics equipment.

The New Design

The new design was created with the goal of producing a biomedical amplifier with an input impedance of 10^{16} ohms, CCMR of 95 to 105 (configurable), ESD protection, configurable frequency response and gain, and a noise floor less than 1uV.

The requirement of obtaining a specified CCMR level was the most difficult aspect of the design. In order to maintain long-term stability we wished to avoid excessive hand trimming of the source or feedback resistors. Further, the reliance upon the CMRR of the differential stage had to be reduced. Since we cannot control the internal matching of the operational amplifiers, ultimate CMRR, the influence of this variable had to be evaluated and reduced. This was accomplished by testing 100 devices per candidate type supplied from three production batches. With this information it was possible to configure the gains per stage and control amplifier CMRR.

The basis of the new series of bioelectric amplifiers is a new semiconductor process. This new process, LinCMOS™ from Texas Instruments, represents a substantial improvement in low power operational amplifiers used in the manufacture of bioelectric amplifiers. LinCMOS replaces the metal gate structure in the complementary metal oxide semiconductor process with a silicon gate. The main advantages, as they apply to biomedical amplifiers, are much enhanced long-term stability, higher input impedance, lower noise, and lower power consumption.

An additional benefit of the process has been the incorporation of input protection to 2000 volts. The form of this input protection is significant in that it prevents loading of the amplifier inputs. The protection scheme is accomplished through the use of complementary MOSFETs across the inputs of the amplifier. While input protection per se is not new to operational amplifiers, previous protection schemes extracted their penalty. The most common form of this protection was that of the input diode. Leakage currents introduced via the diode connection distorted input currents such that the input-bias current specification was no longer valid. When applied to the biomedical amplifier this increased leakage degraded performance substantially.

Amplifier Configuration

The configuration for the new series of amplifiers is illustrated in Fig. 2. A portion of the functional diagram is identical to that used in our in previous example, Fig. 1. The new design essentially adds a new input stage to the basic configuration. In the discussions of the EMG amplifier, a limitation on the input stage gain was noted. This limitation is a function of two electrical parameters of the operational amplifiers. The first of these is the input and output offset component of the input amplifiers. While this error is small, the relative signal levels at this stage are comparatively smaller.

The second parameter is the input offset specifications of the differential amplifier, B5. When we consider that the first error is multiplied by the gain of the input stage and then further multiplied by the differential gain of B5, it is possible for the level of these errors to severely limit the input signal range. The second reason for the inclusion of the extra input range is the effect of the mismatching of the input amplifiers. While not well documented in literature, the distortion effect due to mismatching on the common mode can severely limit the common mode rejection of the total amplifier. Mismatch in the common mode signal as applied to the differential amplifier is added to the difference signal. In the case of the bioelectric signal, mismatch introduces distortion thereby modifying the frequency characteristics. In application, both of these errors account for the loss seen in theoretical common mode rejection while degrading the signal-to-noise ratio.

The addition of the input stage relies on the tight matching and high performance of a dual LinCMOS amplifier. The strategy is to divide the input gain among two stages using a precision amplifier as input. The majority of gain is assigned to the first input stage. Here the smaller error factors multiplied by the gain have a less detrimental effect. The second stage provides the remainder of the gain and uses less stringently specified amplifiers. Here the effect of multiplying a subtly larger error by a smaller gain factor yields a net improvement. The overall effect of the two stages is to increase the maximum allowable input stage gain, thereby achieving a higher ultimate common mode rejection. The reduction on reliance of the common mode performance of B5 reduces the long-term degradation in common mode rejection. A further design advantage of the two input stages is a much greater flexibility in building frequency response profiles for the amplifier.

The circulating current problem is addressed in the new design by the use of extremely high-input impedance operational amplifiers, and low-bias current with 2000-volt input protection. The semi-conductor process used in the manufacturer of the amplifier series yields an apparent input impedance of 10^{16} ohms and maximum 35 nanoampere input-bias current. A biomedical amplifier based upon this new process technology lowers the circulating current contribution to motion artifact below the biological noise floor.

The galvanic couple polarization is minimized by the use of small area ($.5\text{cm}^2$) stainless steel contacts.

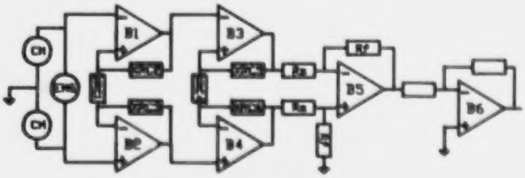

Fig 2

Stephen J. Greelish
Prosthetics & Rehabilitation Group
Liberty Mutual Insurance Company
71 Frankland Road, Hopkinton, MA

Specifications

The specifications of the new design are as follows:

Supply Voltage	Split rail, plus/minus 5 to 16 Volts.
Power Consumption	2 mW (quiescent), 6 mW (average)
Supply CMRR	70 dB, RF decoupled
Input CMRR	95 to 105 dB
Input Impedance	10^{16} ohms
Input Range	.5 to 1500 uV
ESD Protection	2000 V referenced to common
Noise Level	.1 uV (low pass configuration), .5 uV (bandpass configuration)
Gain	Configurable with a maximum of 5000, subject to the filter profiles.
Prefilter	Configurable DC to 1000 Hz, highpass, lowpass, bandpass.

The amplifier series features a common circuit board for the various models. This circuit board, actually flex circuitry, is used to directly attach surface mount devices. The surface-mounting construction is responsible for the small size of the amplifier. A completed amplifier circuit is installed in an injection-molded package which measures 17.2 X 26.3 X 5 mm. This package profile is designed to meet the most stringent biomedical amplifier requirements, that of the EMG electrode.

Discussion

For myoelectrically controlled devices, the new package presents zero clearance mounting. For the prosthetist this means that no space between the inner and outer socket is required for amplifier mounting. The amplifier and its flex-circuit cable can be mounted flush on the inner socket while still projecting through the inner wall a sufficient distance to insure proper contact. For application in other disciplines, the package is sufficiently small, when compared with current biomedical amplifiers, as to present no difficulty and in some cases, a significant improvement.

The primary difference in amplifier specifications for electrocardiography, electroencephalography, and electromyography are frequency response and system gain. This is accommodated for in the basic design by allowing configuration of filter characteristic and stage gain. The process of component selection and simulation testing is handled by computer.

Initially, the Liberty Mutual Research Center will offer five bioelectric amplifiers, each targeted to a different application. The five models are characterized by their filter response as follows: DC to 45 Hz (EEG), DC to 550 Hz (EMG), 10 Hz to 100 Hz (ECG), 10 Hz to 1000 Hz (general) 45 Hz to 550 (EMG).

QUANTITATIVE ASSESSMENT OF THE IMPORTANCE
OF ELBOW PROSTHESIS DYNAMIC BEHAVIOR
IN THE PERFORMANCE OF MANUAL TASKS

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ABSTRACT

Proposals to improve the elbow function of arm prostheses must consider whether such work would make a useful difference in performance, given the other likely sources of impairment inherent in prostheses. This paper reports an experiment designed to isolate the benefit of elbow dynamics.

The behavior of a myoelectric elbow prosthesis was mimicked in an intact limb, by use of a wearable braking fixture that mechanically impedes elbow motion. A test was designed which evaluates control of force and motion in a functionally meaningful task. In results of this test for one subject the performance of the mechanically impeded intact limb clearly reproduces the major kinematic and mechanical features of the performance with the prosthesis. This result suggests that the dynamic performance of elbow prostheses has a major impact on task performance, and must be addressed in new designs if they are to address the performance limitations of current prostheses.

INTRODUCTION

Does the dynamic behavior of an elbow prosthesis have a significant impact on the functional capability of the amputee using it? The limited functional capability of amputees using elbow prostheses may also be attributable to many other factors, including limited sensory feedback, limited grasping capability, difficulty of generating control signals, and method of attachment to the body. Why expect any improvement in an amputee's functional ability to result specifically from working on the elbow behavior?

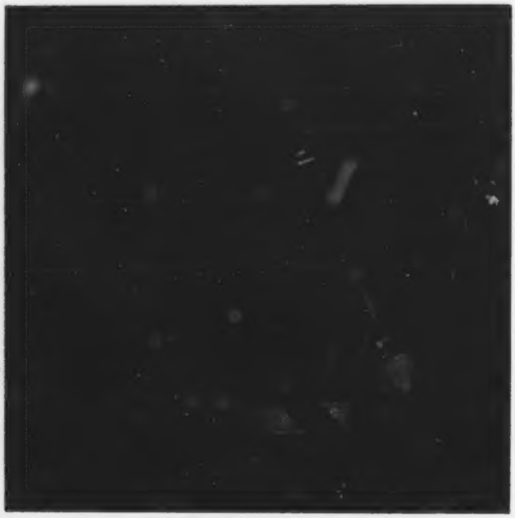

Figure 1 — the IMPEDER used to modify elbow joint behavior.

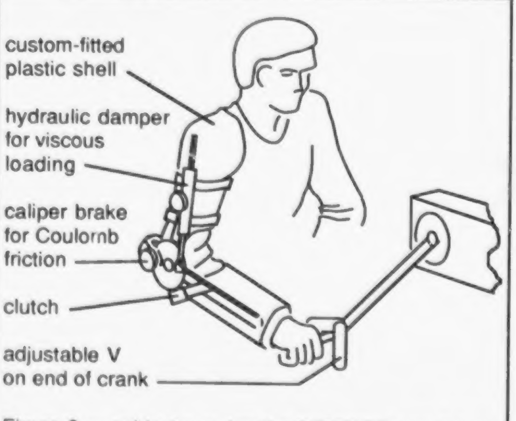
custom-fitted plastic shell
hydraulic damper for viscous loading
caliper brake for Coulomb friction
clutch
adjustable V on end of crank

Figure 2 — subject wearing the IMPEDER arm fixture while operating the special crank.

The experiment reported here is an initial reponse to that question. The approach taken here was to try to isolate the effect of elbow dynamics by mimicking the dynamic behavior of the prosthesis elbow joint in an otherwise unimpaired intact limb. Since the other possible sources of functional impairment present in a prosthesis are absent in this case, any aspect of the prosthesis's functional impairment which is recreated in this modified intact case can reasonably be attributed to the impairment of elbow dynamic behavior.

METHODS

Protocol

This experiment tested three different types of arms: an intact arm; a Boston Arm myoelectric prosthesis; and an intact arm modified by a wearable fixture to behave similarly to the Boston Arm. These three experimental cases were all tested in one subject: a unilateral amputee, who performed the prosthesis-using case with a Boston Arm on his right side, and performed the two intact-arm cases with his intact left arm.

Mimicry device. The device to modify the intact arm, dubbed IMPEDER (Intact-arm Modifier for Prosthesis Elbow Dynamics Emulation Research) (Figure 1) is a hard-shell splint, hinged at the elbow, with two adjustable brakes to mimic the Boston Arm's dynamics: to mimic velocity control, a viscous damper so that muscle effort is expressed as velocity; and to mimic the property of remaining stationary for input below a preset threshold (1), a disc brake applying constant friction .

Task. The subject operated a special kind of hand crank, without a handle attached. Instead, the crank arm ends in a V-shaped fixture. The subject moves this crank with an unattached "handle" which he presses into the V (Figure 2). With a prosthesis, the subject uses a modified prosthesis hook which engages the V the same way.

Since the handle is only partially constrained, it will stay in the V only under forces within a limited range of angles. The angle between the branches of the V can be adjusted to vary this range and change the difficulty of the task. Three different V angles were tested, with values of 120 degrees, 150 degrees, and 170 degrees. For each of the three arm types and each of the three V angles, three or more runs of the task were recorded.

The task was to move the crank from its bottom position to its top , through the semicircle nearer the subject. Physical strategy and speed of motion were left up to the subject. The load for the task was simply the torque due to the weight of the crank itself; the maximum tangential force needed was 4.7 N.

This motion was chosen to include two points of possible difficulty: those where the angular motion of shoulder or elbow must reverse. Coordination of the multi-joint motion becomes more difficult at these reversal points.

Instrumentation

Kinematic information was recorded by the laboratory's TRACK system, which computes the positions and orientations of body segments, using Selspot® cameras to track infrared light-emitting diodes on them (2). Arrays of these diodes were mounted on the forearm and upper-arm segments of the arm fixture or prosthesis used in the task, and on the radial arm of the crank. Force information (tangential and radial components) was recorded from strain gauges in the base of the V fixture.

RESULTS AND DISCUSSION

The modifications made to the intact arm's elbow dynamics did recreate most essential features of the difference between prosthesis task performance and that of the unimpeded intact arm. The degree to which this mimicry succeeded strongly suggests that elbow joint dynamics is indeed an important limit in the task performance of prostheses:

Plots of selected variables for three typical runs from the 150-degree V series are shown in Figure 3.

Joint angles. The modification of elbow joint dynamics causes a resemblance to prosthesis motion in the intact elbow and shoulder joints. For the unimpeded intact arm, both shoulder and elbow angle curves are smooth, sinusoid-like shapes. For the prosthesis these motions are much less smooth: the reversal of the elbow angle shows an abrupt stop and start separated by a static interval, and the shoulder angle shows some irregularities around the same time. The angle curves for the impeded intact arm strongly resemble those for the prosthesis in both of these respects.

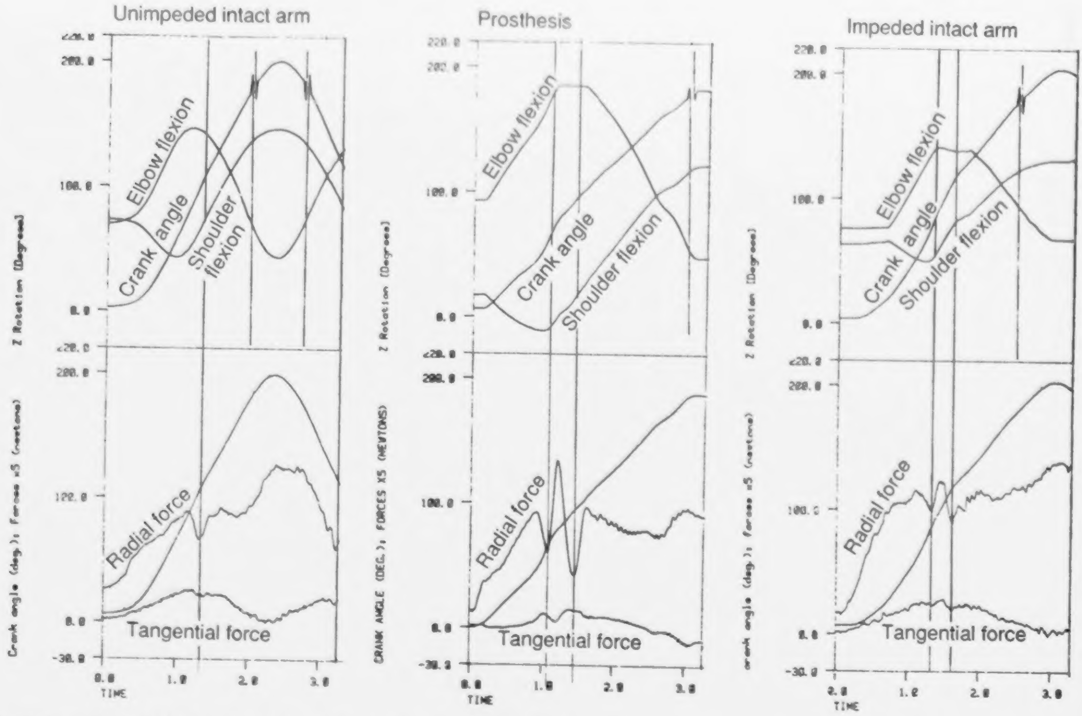

Figure 4 — a typical set of results. (Note: shoulder and elbow angles are shown multiplied by two, to fit plot scaled for crank angle. Zero values for arm joint angles are defined as those of an arm hanging relaxed at the side of the sitting subject.)

End-point performance - motion and forces. The raising of the crank - the task itself - also shows a similarity between prosthesis and impeded intact arm. With the unimpeded intact arm the crank angle follows a very smooth rising curve. With both the prosthesis and the impeded intact arm, this curve becomes uneven midway up the upswing, approximately at the time of the elbow reversal.

This unevenness is necessarily the effect of fluctuations in the tangential force by which the crank is raised. In both the prosthesis and the impeded intact arm these fluctuations in tangential force are much greater than in the unimpeded intact case. They usually appear to be coupled to marked fluctuations in the radial force, which is the predominant component of the force the subject exerts on the crank.

Plots of radial force show a conspicuous and frequently-repeated pattern during the middle of the upswing. While the force generally increases until halfway up and then decreases, certain sharp drops are superimposed on this underlying shape:

In the unimpeded intact arm there is usually a single brief drop shortly after elbow reversal.

In the prosthesis, instead of a single sharp notch, there are usually two very sharp and deep notches, somewhat earlier than in the intact case so that each notch usually precedes one "corner" of the elbow reversal (halt of flexion, or start of extension) by 100-300 ms.

For the impeded intact arm the pattern is similar to that for the prosthesis: the radial force usually shows a pair of notches, less pronounced than those in the prosthesis runs, but timed similarly with respect to the elbow reversal points.

CONCLUSIONS

The use of the impeding fixture did succeed to a remarkable extent in recreating in an intact arm the qualitative differences between unimpeded intact arm performance and Boston Arm prosthesis performance. These results show that, in this task, a change in elbow joint behavior alone has a major impact on performance in the intact arm. The dominant nature of this effect in the intact case strongly suggests a similar importance of elbow joint behavior in the performance of the prosthesis itself - that much, maybe most, of the irregularity in the prosthesis's performance of this task arises from the difference in elbow joint behavior between the prosthesis and an intact arm.

ACKNOWLEDGMENTS

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MAKING THE CASE FOR BODY-POWERED UPPER-LIMB PROSTHESES

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ABSTRACT

The key question is: if an upper-limb amputee has sufficient body power, why should he/she be fitted with an externally powered prosthesis? There is no easy answer. The state of the art is that fitting is a complex situation filled with trade-offs in what prosthetic components can offer. Hybrid fitting, or "taking the best of each", has become a common and useful answer to the dilemma. The real answer is to conduct a thorough assessment of each amputee's needs and then to draw on all technology available to meet those needs so each amputee can exercise his/her maximum potential.

INTRODUCTION

As shown in Figure 1, the concept of using a shoulder harness to transmit body power to operate an upper-limb prosthesis was established by Peter Ballif in 1812 (1). The conventional arm prosthesis has existed in its present form largely unchanged since World War II. It is "tried and true" and used by approximately 90% of arm amputees wearing prostheses.

Of the 10% of arm amputees who use externally powered prostheses, most have body-powered systems for backup or trade-off use. This means that almost all arm amputee wearers have body-powered upper-limb prostheses.

Then why is all the fuss, work and funding going into the development of externally powered upper-limb prostheses?

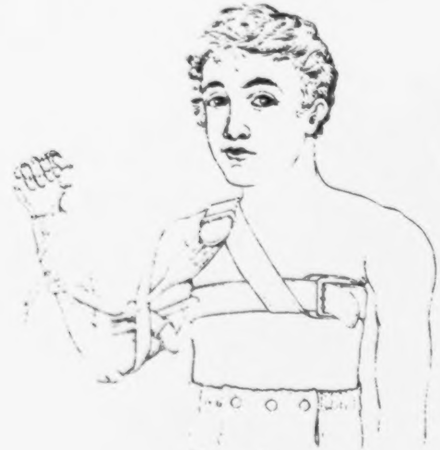

Figure 1
Ballif Arm of 1812

STANDARD PROSTHESES

Figure 2
Body-Powered Prosthesis
for above-elbow amputees. (2)

Figure 3
Externally Powered Prosthesis
for above-elbow amputees. (3)

COMPARISON

Body-Powered Arm Prostheses	Externally Powered Arm Prostheses
Lighter	Heavier
Faster	Slower
More sensory feedback	Less sensory feedback
Lower cost	Higher cost
Less repairs	More repairs
More harness	Less harness
Less comfort	More comfort
Less cosmesis	More cosmesis
Archaic looking	More high-tech looking
More energy effort	Less energy effort

CLOSER LOOK AT OTHER ISSUES

Terminal devices. People frequently associate hooks with body-powered prostheses and hands with externally powered prostheses. With the recent development of externally powered hooks (4), however, an easier interchange of TD's is possible and makes the decision of TD separate from the decision of power source.

Non-users. About 50% of the estimated 100,000 arm amputees in the USA choose not to wear prostheses (5). To the author's knowledge, no surveys have been conducted regarding why they do not. Best guesses are that these people value the sensory feedback from their own residual limbs, and they do not like the bother of wearing prostheses.

High-level amputees. The real incentive for external power was originally high-level, bilateral, arm amputees who simply do not have enough body motions to operate all the prosthesis motions required. The Thalidomide children in Europe and high-voltage power line or farming accidents in the USA were typical instigators of work in externally powered limbs. This work now has been carried over to lower-level, unilateral, arm amputees who may have sufficient body power but may benefit in other ways.

Early fittings. Malone, et.al. (6) have put forth the "Golden Period" of 30 days within which an arm amputee should be fitted after amputation. They correlate early fitting with successful acceptance and use of prostheses.

Fitting body powered prostheses first. Malone, et.al., Meier, et.al. (7), and others advocate the fitting of a conventional, body-powered arm prothesis first and then the fitting of an externally powered prosthesis if indicated.

COMPLEX ISSUES

The fitting of prostheses for arm amputees becomes somewhat complex. It is laced with trade-offs of hook versus hand, body power versus external power, and various types of socket fittings. It becomes a balance of values of function versus comfort versus appearance for each amputee.

HYBRID FITTINGS

The answer in many cases to the complex issues is the hybrid fitting of body-powered and externally powered components. Such fittings are becoming more useful and common as the armamentarium of prosthetic components increases. It is a "mix and match" of components to best address the needs of individual amputees.

CONCLUSIONS

One may ask, "When an amputee has body power, why use external power?" As is obvious from the pro's and con's of the two types of systems, each has advantages and disadvantages. The really important issues are that: 1) the prosthetics team conduct a meaningful assessment of each arm amputee to determine needs and desires, and 2) they draw from all components and technology available to allow each amputee to conduct his/her life as fully as possible.

ACKNOWLEDGEMENTS

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7. Meier, Robert, MD; Diane Atkins, OTR; and Alvin Muilenburg, CPO of the Houston Center for Amputee Services. (Dr. Meier and Ms. Atkins are now at the University of Colorado Health Sciences Center in Denver.)

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NEW DESIGN FOR A BODY-POWERED PROSTHETIC PREHENSOR

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ABSTRACT

Current prosthetic prehensors offer advantages either in function or in appearance but seldom are satisfactory in both areas. A new prehensor has been designed which addresses both factors simultaneously. It features a single moving "thumb" and a stationary "palm", voluntary-closing action, and internal actuation. Also, the finished prototype will feature a new type of locking/cord takeup mechanism which allows a passively closed grip with single-motion unlocking. The prehensor design is described herein.

INTRODUCTION

An upper-limb amputee today is faced with a "form vs. function" dilemma when choosing a prosthetic prehensor. At one end of the spectrum is the cosmetic hand, which somewhat replaces the anatomical appearance but is very limited in function. At the other extreme is the classic Dorrance 10X hook, which is still the gold standard in function but is almost universally regarded as unsatisfactory in appearance.

Between the extremes of pure form and pure function fall only a small number of devices, including myoelectric hands; the Hosmer Contour-hook; the A.D.E.P.T. prehensors of TRS Corp.; and the CAPP prehensors designed by the late Carl Sumida. The design presented here is part of a project at the Rehabilitation Engineering Center of Children's Hospital at Stanford. The goal is to end the "form vs. function" dilemma by developing a prehensor which is a handsome tool, neither hook nor hand.

MATERIALS AND METHODS

The following specifications were developed in cooperation with Maurice LeBlanc, director of the Rehabilitation Engineering Center; and Carib Nelson, owner of Perspectives Design Company in Palo Alto, California.

Function

The key aspects of grasp were found by consulting reference works on the biomechanics of the hand (1,2,3). Also, minimum force and excursion requirements were obtained from the standard reference text (3). The following specifications were outlined:

1. Operation with one degree of freedom (a 2-inch pull on the harness cable)
2. Minimum of three functional grips:
   Two-finger pinch
   Three-jawed chuck
   Passive hook grasp
3. Voluntary-closing action
4. Ability to hold 3-inch diameter cylinder and irregularly-shaped objects
5. Fingertip force of at least 10 lbs. with a 30 lb. input
6. Speed, smoothness, reliability

Appearance

An anatomical approach to form was taken. While imitation of the human hand was not the goal, it was felt that the prehensor should parallel the familiar shape of the hand so as to be comprehensible to the observer. At the same time, however, the artificial nature of the device should not be disguised but rather presented plainly to avoid embarrassing ambiguity. A long series of sketches and group evaluative sessions explored variations based on the following specifications:

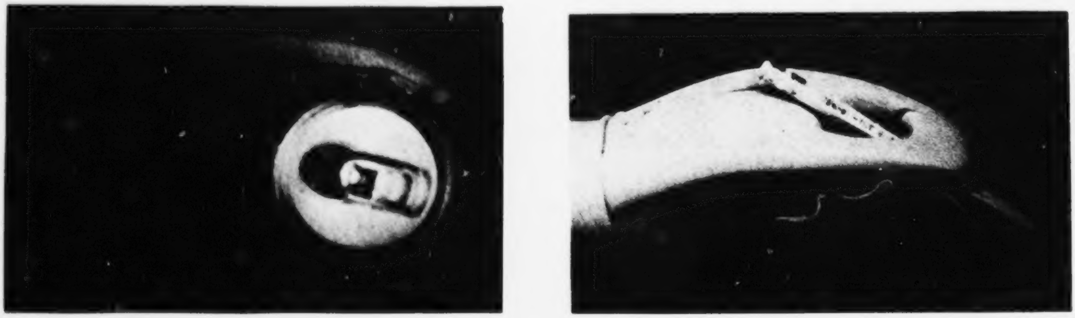


Figure 1
Life-size acrylic model of the prehensor in two different grip modalities

1. "Neither hook nor hand": a handsome tool which neither deceives nor offends the observer
2. Internal actuation to allow endoskeletal limb with soft exterior
3. Colors and materials which are pleasing to look at and to feel

RESULTS

The final design (figures 1 and 2) features an approximately anatomical silhouette which is simplified, stylized, and made symmetrical (so that the same prehensor works on the left or right side). In the closed position, the prehensor is streamlined for easy insertion into a pocket.

A gripping configuration was developed which allows all three grips mentioned in the specifications above, using a single degree of freedom. The basic shape is a curved "palm" consisting of two columns which merge distally to form a single "fingertip" for fine manipulation using a two-finger pinch. The more proximal columns form two fingers for the three-jawed chuck grip. The opening between these columns serves the dual purpose of enhancing visibility of held objects, and as a purchase for pencils, knife handles, etc. In the fully open position, the palm and opposing "thumb" follow the curvature of a 3-inch cylinder or ball. When fully closed, the gap between thumb and palm will accommodate a 3/4-inch suitcase handle. The regularly-spaced bumps on the palm and thumb will be made of a flexible rubber to allow grasping of a variety of irregular shapes.

The passively-closed hook grasp (for suitcases, etc.) will be achieved in the final prototype by means of a new type of locking mechanism (figure 3). Its purpose is to allow the passive grip while at the same time avoiding the annoying two-motion unlocking which characterizes such prehensors as the APRL hand. The new lock works as follows:

1. As the wearer pulls on the harness, lever A moves thumb B into the closed position. Toggle C snaps up into a notch in the hub of the thumb, locking it closed. This is the passive hook grasp.
2. The wearer now can relax on the harness, and lever A is free to return to the open position, taking up cord as it does so. Just as lever A reaches the fully open position, cam D (which is mounted in lever A) moves past toggle C and rotates up against it.
3. Now, when the wearer wants to unlock the thumb, he/she simply pulls on the harness. In the first fraction of an inch, cam D pushes one end of toggle C up so that the other end moves out of the notch in the thumb. The thumb, free to move, springs open to meet lever A. The wearer then may re-close the prehensor with a continuation of the same motion which opened it, a distinct advantage over previous locking mechanisms.

Materials and colors for the final product are still being investigated. A sturdy, lightweight plastic with a textured surface is currently favored. Neutral colors such as beige or warm gray are being explored as alternatives to the standard "fleshtone" of cosmetic hands. Again, the goal is to make the artificial nature of the prehensor clear but not shocking to the observer.

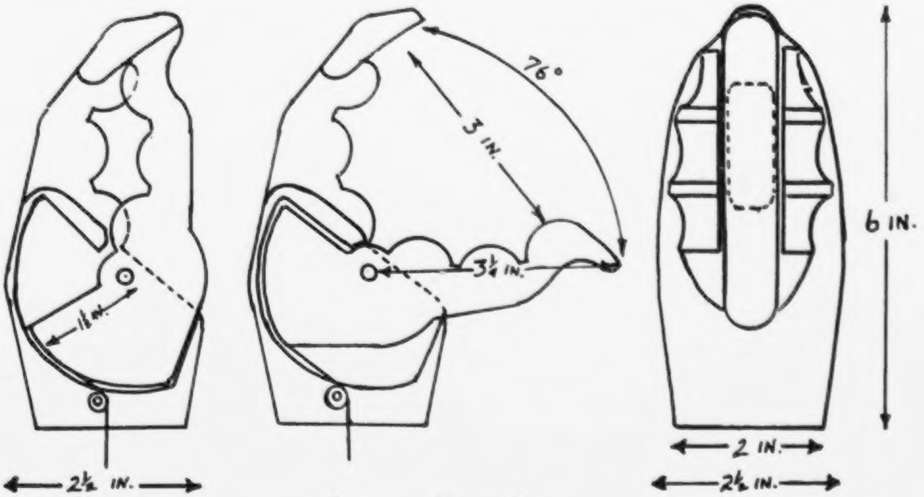
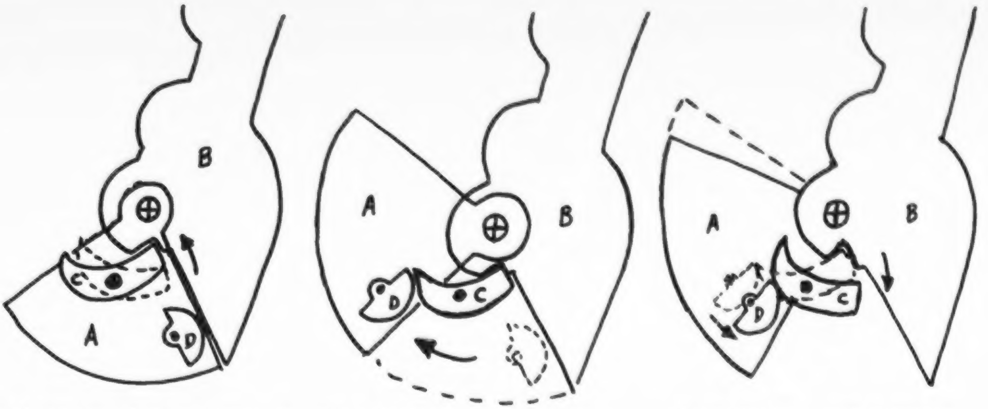


Figure 2
Cutaway side views of the prehensor in open and closed positions, and front view in the closed position (locking mechanism omitted)



1) Locking: Toggle C springs into notch in thumb B

2) Relaxing: Lever A moves cam D past toggle C

3) Unlocking: Cam D pushes one end of toggle C up so that other end goes down and out of notch in thumb B

Figure 3
A simplified sketch of the prehensor locking mechanism

CONCLUSION

The prehensor design presented here attempts to integrate both optimal function and pleasing appearance into one tool for the amputee. Along with two other designs from the project, this model will be evaluated by means of a personally-administered survey of amputees, prosthetists, orthotists, and members of the general public. Subjective assessment of appearance, function, and acceptability will be obtained.

Following this preliminary evaluation, the prehensor will be modified in accord with the recommendations from the survey. A working prototype will be constructed and tested in a field trial by volunteer amputees. The final successful design will be presented for future manufacture and marketing.

ACKNOWLEDGEMENTS

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THE RESEARCH ON
A TOTAL ARM ELECTRICAL POWERED PROSTHESIS
-- MOTION PROGRAM --

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ABSTRACT

In order to develop a total arm electrical powered prosthesis affordable for the practical use, it has been needed to develop a rigid shoulder mechanism with three degrees of freedom, hand mechanism usable for a daily various kinds of job and a compact and highly reliable control apparatus. On the other hand we have to shorten a period for the development of individual prosthesis system which has been taken a long time because degree of impairment of each patient, their needs for the job and their wish for the prosthesis are different. For these problems, we set following four targets.
(1) Compact and highly rigid shoulder mechanism.
(2) Hook type hand for the job and cosmetic type. These both types are driven by DC motors and easily changable.
(3) Smaller multiple microcomputer sets and upper grade personal computer for development support.
(4) CAD and/or artificial intelligence techniques to shorten the development period and the flexible accomodation.

1. INTRODUCTION

To acquire the total arm electrical powered prosthesis for the practical and the actual daily life use, we set these four points as a development target.
(1) Development of new type shoulder mechanism.
(2) Hands easily changable according to its job.
(3) Control system by a multiple microcomputer for the flexible and reliable operation.
(4) Establishment of prosthesis support system for the development and training introducing CAD, AI and simulation techniques.

The following computer applied approaches are taken from the planning to the operation of prosthesis.
(a) Adjustment of arm length fits for the patient and the contact of prosthesis and socket using CAD technique.
(b) Arrangement of arm control programs, generation of motor drive data, selection of operating apparatus and the command set.
(c) Emulation of control program for its program debugging and valuation using upper grade personal computer.
(d) Operation exercise or training by a personal computer prosthesis operation simulator.

2. MECHANISM AND CONTROL HARDWARE
2-1 SHOULDER MECHANISM

Fig. 1 shows a shoulder mechanism of our prosthesis. The lifting mechanism is a link mechanism which principle is presented at the last RESNA in 1985. The merit of this mechanism is to be able to gain its maximum torque when upper arm is at the angle of daily movement, which is nearly 60 degrees. As shown in the figure this link mechanism is used for the forward and the sideward movement. The mechanism is composed of an universal joint and a ball screw. The third degree is a rotation at the upper arm. In total the shoulder has three degrees of freedom.

2-2 HAND

It is hard and not economical to provide a multi-functional electrical powered hand. Instead we developed two types of hand which are decorative and for the job. The decorative one has an appearance of natural human hand and fingers fits well to the object since thumb and next two fingers have a spring at the joint. For the job type we provided higher power and its shape of hook which make various kinds of job possible. Both type are driven by DC motors.

2-3 MICROCOMPUTERS FOR THE PROSTHESIS CONTROL

The prosthesis controller is made smaller than our convensional board type. The computer is hybrid type includes Z80 CPU(4MHz system clock), CTC unit and RAM 2KBytes. Program ROM and motor drive amplifiers are external. We use 4 set of this hybrid computer. One is for the operation command interpretation and motion calculation and the other 3 set are for the motors' position control. Fig. 2 shows a block diagram of the controller.

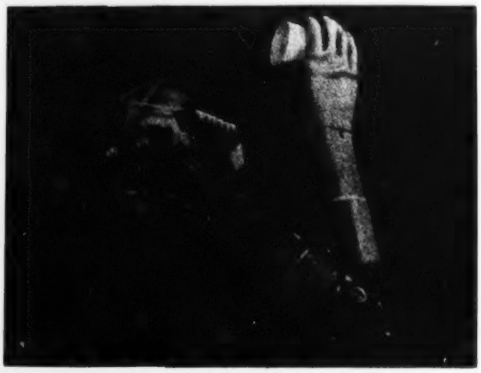

Fig. 1 Shoulder mechanism with two linkages

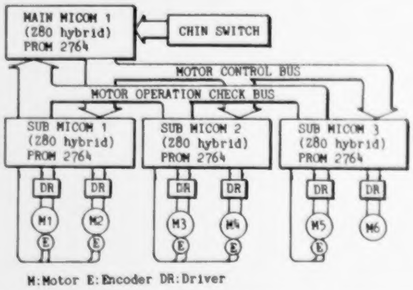

Fig. 2 Block diagram of prosthesis controller

3. PROSTHESIS SYSTEM SUPPORT

The patients have various needs for the prosthesis because the environment around them and their physical condition are different. To provide a prosthesis in reasonably short period we introduced prosthesis support through the whole level of development. Fig. 3 shows a support flowchart from the planning to the field test.

3-1 DESIGN OF EXTERNAL ARM APPEARANCE

We have been utilizing CAD technology to get a fine decorative appearance for the arm. The process to get arm model is, for example;
(1) The natural human arm is measured by a three dimensional measuring machine applicable to the human skin directly. Or plaster model is measured instead.
(2) The measured data is processed by expanding or shrinking in order to match to the specified prosthesis appearance.

This measuring machine can be operated automatically in a point-to-point mode with a certain pitch. After some data modification wax material may be engraved using the same measuring machine by replacing measuring probe by an end mill cutter.

In a similar way, plaster model of patient's body is measured. The positive body model is created from the measured data, then the contact position for the prosthesis and the frame shape is discussed and determined.

Fig. 4 shows an example of measured body model. (conditions; pitch: 10mm, total measured points: 12000, measuring time: 120min., measuring accuracy: ±0.05mm)

3-2 SELECTION OF CONTROL PROGRAM

For many years we have been developed various types of prosthesis. At present, accordingly, our problem is how to select and arrange the control program pieces which is divided in module as a macro. Operation command apparatus and its command set is determined according to the degree of patient's ability and the jobs he/she wants by a repetition of IF THEN rule known as a technique in artificial intelligence.

3-3 FUNCTIONAL CHECK OF CONTROL PROGRAM

The prosthesis controller has a poor debugging functions because its primary target is to be compact. In order to support this shortage, we use following tools.
(1) Symbolic debugger for Z80 CPU.
(2) Emulator by a higher grade personal computer. From this tool prosthesis motion simulator is accesible which is described below.

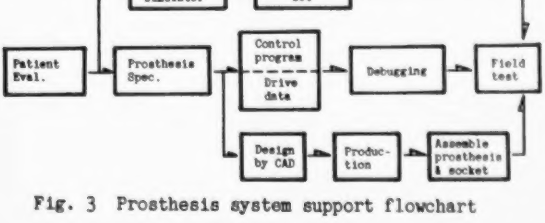

Fig. 3 Prosthesis system support flowchart

Fig. 4 An example of measured body by CAD

3-4 PROSTHESIS MOTION SIMULATOR

When the size of prosthesis and the degrees of freedom are determined, its shape can be expressed in the computer and displayed on the CRT by coordinate transformations. Since the prosthesis has a multi joint arm structure, each part is coordinate transformed one by one from shoulder joint through the arm, then finally projective transformation is operated. Even if the actual prosthesis is not yet finished producing this simulator is applicable for the operation training by connecting actual input apparatus.

4. CONCLUSION

As we have got a rigid mechanism for the shoulder , selective hands and the reliable, flexible controller system by a microcomputer, we introduced a total prosthesis support system utilizing an advanced technology includes CAD, AI, and computer simulation.

A few themes are still under study for the better efficiency. We think with this total prosthesis support system we can provide a prosthesis usable for the actual job for the patient who needs eagerly.

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DO WE NEED A PROSTHETIC PREHENSOR WHICH IS NEITHER HOOK NOR HAND?

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Children's Hospital at Stanford

ABSTRACT

Currently, arm amputees have a choice of a hook or a hand. There are compromises between the two options. The hook is more functional, and the hand is more cosmetic. Some amputees solve the dilemma by having one of each and interchanging them as work and social situations dictate. Arm amputees prefer to use one prehensor which is functional, is attractive, and does not necessarily look like a hand. Then, why not have a prehensor which is neither hook nor hand? One significant departure from standard hooks and hands has been the CAPP I and II prehensors designed by Carl Sumida at UCLA. His creative work has demonstrated the possibility of designing prosthetic prehensors which function well and are handsome, too. His pioneering work has opened the doors to promising new options for upper-limb amputees. Design ideas for new prehensors are explored herein.

INTRODUCTION

A typical hook and hand are shown in Figures 1 and 2. Upper-limb amputees commonly choose a hook, especially when function is more important. Some choose the hand, especially when appearance is paramount. And some elect to have both a hook and a hand to interchange them as desired.

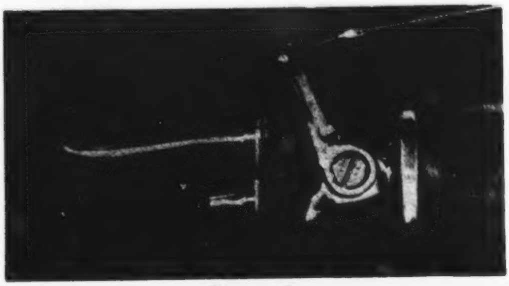


Figure 1
Typical Hook

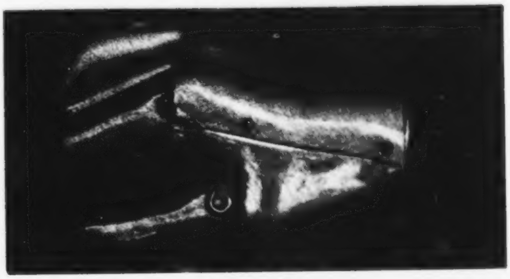


Figure 2
Typical Hand

DESIRES OF UPPER-LIMB AMPUTEES

Amputees prefer to have one prehensor rather than two which must be interchanged. There are many prosthetic hands in closets which bear testimony to this preference.

In a recent survey (1) upper-limb amputees expressed the desire to have a prosthesis which looks attractive and inconspicuous but which does not need to look human. They seem to be saying, "I don't want to disguise the fact that I'm an amputee, but I want an upper-limb prosthesis which looks nice for its own sake". There will always be amputees who either want to draw attention to the prosthesis or try to disguise the fact that they are amputees. However, the majority appear to fall in between and want a prosthesis which is smooth, soft, attractive, but not necessarily human looking.

IDEAS FOR NEW PREHENSORS

Why not have a prehensor which is neither hook nor hand? The idea is to design a prehensor which is as functional as a hook, is esthetic. and does not have to look like a hand. The incentive for the idea comes from the desires of arm amputees and also from the difficulties with cosmetic gloves for hands. Besides the problems of staining, tearing and the additional force required to open the hand, cosmetic gloves lack the blood supply of the human hand and inherently look dead. In fact, many people feel that the closer to human we make the cosmetic gloves, the spookier they appear. So, attempting to improve cosmetic gloves may not be the best approach.

A significant departure from traditional hooks and hands has been the CAPP prehensors designed by the creative and now deceased Carl Sumida, CP (2). Figure 3 shows a wonderful evolution of design from the standard Dorrance 5X hook to the CAPP I prehensor for children. Figure 4 shows the recent CAPP II prehensor for adults now being produced for clinical trials. Some of the interim designs for the CAPP I prehensor are elegant. There is no reason why we cannot design a prehensor which functions well and looks good too.

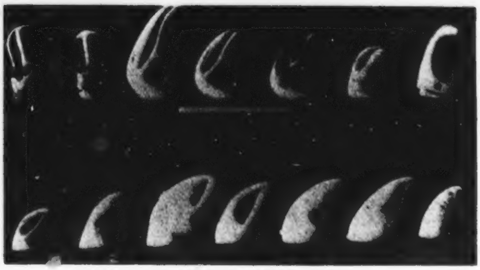


Figure 3
Evolution of the CAPP I

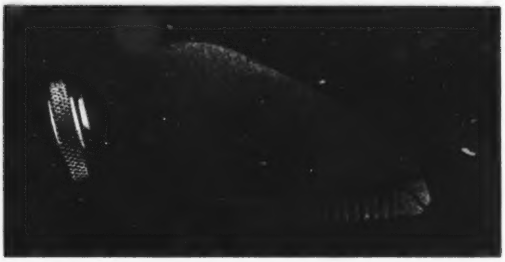


Figure 4
New CAPP II Terminal Device

DESIGN SPECIFICATIONS

In keeping with the desires of upper-limb amputees, the design goal is to develop a prehensor which is functional and looks good, too. Also, to get all the control hardware inside the prosthesis, the prehensor must be internally actuated.

Function: good grasp, fast, light, reliable, durable, replaceable, "center pull" versus "outside pull", compatible with wrist function, allowing sensory feedback for body-powered systems, and approximate length of human hand.

Appearance: handsome, neither hook nor hand looking, internal mechanism, and attractive in motion.

PRELIMINARY DESIGN IDEAS

Figures 5-8 show four ideas which have been generated from preliminary work. All except Figure 7 are both voluntary opening and voluntary closing.

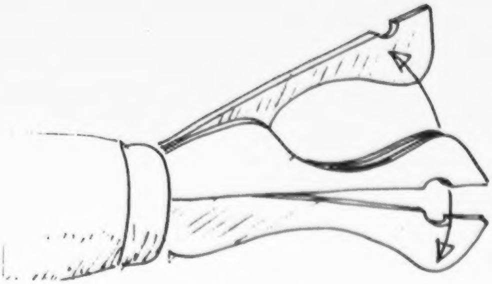


Figure 5
Pass Through Grip by C. Nelson
(with two types of grasp)

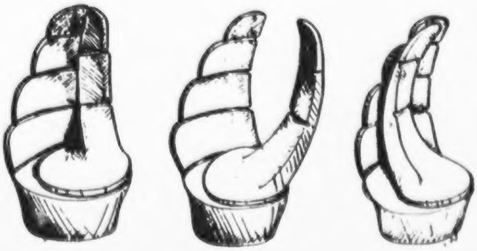


Figure 6
Circular Grip by C. Nelson
(with two types of grasp)

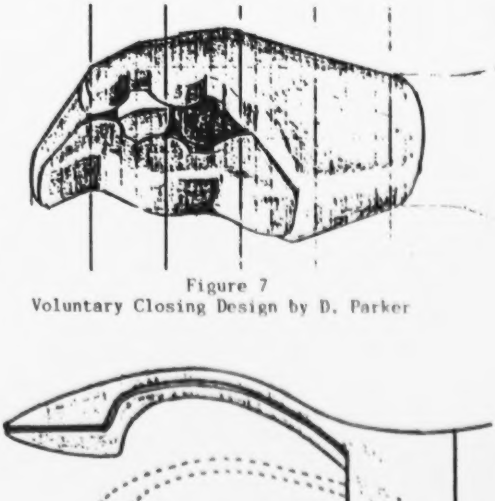
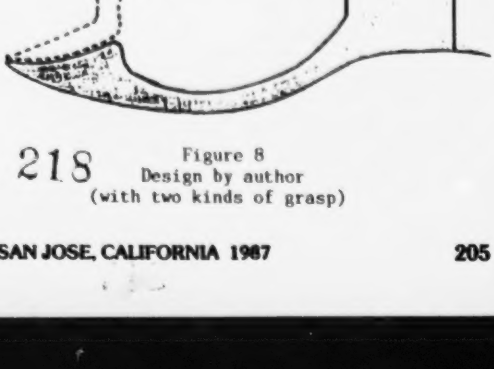


Figure 7
Voluntary Closing Design by D. Parker



218

Figure 8
Design by author
(with two kinds of grasp)

FUTURE WORK

This work is being continued. Models will be built of promising ideas and then evaluated. Prototypes will be built of one or two to test with amputees, as well as waiting for results of clinical trials of the CAPP II.

ACKNOWLEDGEMENTS

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Douglas Parker is a second year medical student at Stanford University Medical School who has a keen interest in upper-limb prosthetics. Carib Nelson is a product designer with keen ideas who has his own company, Perspectives, in Palo Alto.

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AN ADAPTIVE HANDLE FOR A SAFETY RAZOR

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Rehabilitation Institute of Chicago

ABSTRACT

The design of an adaptive handle for a commercially-available safety razor is presented. The handle has been disigned for use by individuals with C5-6 level quadriplegia. Two variations of the lightweight handle are described. For those using a flexor hinge orthosis, the handle provides an increased diameter for grasping. Within the handle, the razor is free to pivot, allowing it to follow the contours of the face. The handle has been further modified for use with a definitive long opponens orthosis. The addition of an aluminum tab allows the razor handle to be slipped into the appliance slot of the orthosis. The aluminum tab pivots on the razor handle so the user can independently change the angle of the razor to increase access to all facial areas. Fabrication details are provided so that these handles can be duplicated.

Persons with C5-6 spinal cord injuries typically are unable to achieve independence in shaving. There are few shaving equipment options available for this population. Some of these individuals have achieved independence in shaving by using an adapted electric razor. Other individuals use safety razors adapted with orthoplast or rely on attendant care to meet this need. Clinical observations indicate that those who have attempted to use an orthoplast-adapted safety razor have frequently been frustrated by the difficulty associated with reaching all facial areas. The electric razor also has disadvantages. It requires strength and endurance to maintain it in a functional position. Further, it does not provide a close shave and is often not the method used by the individual prior to the onset of the disability.

A well-groomed appearance is often important in marketing ones abilities in the community and workplace. A clean shave may also aid in improving a person's self-esteem. For quadriplegic males, independence in oral/facial hygiene is not complete until the skill of shaving is gained. The Adapted Shaver was developed to provide an option for independent shaving to C5-6 quadriplegic males. This method has been found to decrease the need for assistance from a personal care attendant. It has been proven to be effective in providing a close shave while assisting in the maintenance of upper extremity strength and endurance through daily shaving activity.

DESIGN

The Adapted Shaver was initially developed in early 1985 by the Rehabilitation Institute of Chicago's Rehabilitation Engineering Department. It was evaluated with clients seen through RIC's Occupational Therapy Department. Modifications to the basic design have taken place since that time. The goals of the design were to provide the client with a lightweight, durable system which would allow a safety razor handle to pivot within the hand to access all facial areas. Cost was another consideration, and included in the design is the capability of transferring the adaption to another razor handle of the same type, if necessary.

The razor chosen for adaptation was the Atra by Gillette. This particular model was chosen because of its availability and the popularity of some if its features. This is a light weight razor and its cartridge blades can be independently engaged and disengaged from the handle.

FABRICATION

The basic Adapted Shaver design uses materials which are readily available:

Gillette Atra Razor
Delrin hollow rod
  1/2" ID, 1" OD
Aluminum shaft collars (2)
  1/2 " ID

The tools needed to fabricate the adaption are found in most Rehab Engineering Departments or Occupational Therapy Departments:

Band saw or hack saw
File
Drill press
Hand vise
17/32" drill bit
9/64" allen wrench

1 - Using a band saw or hack saw, cut a 2-1/4" length of the delrin hollow rod. Round the edges of the rod using a file.

2 - With the length of delrin secured vertically in a hand vise, drill out the center of the rod using the 17/32" drill. This increase in the inside diameter of the rod is necessary to allow the shaver handle to pivot freely. Note: The hand vise should be held securely and have channels in the jaws which allow a round piece of material to be held vertically in a safe manner.

3 - Install one aluminum collar near the top of the razor handle. It may be necessary to increase the "C"-opening of the collar in order to slip the collar onto the handle. This can be done by removing the collar's screw and spreading the clamp with a screwdriver.

Slip the delrin hollow rod onto the razor handle, followed by the other aluminum collar. Position the collar such that the delrin hollow rod rotates freely about the handle.

Another version of the adapted shaver has recently been developed for those quadriplegic individuals using definitive long opponens orthoses. This type, commonly referred to as a wrist-hand orthosis, provides a slot located between the thumb and forefingers for the insertion of appliances. A tab has been provided on the adapted shaver which fits into this appliance slot. The tab can pivot on the handle, thus allowing the user to independently adjust the angle of the razor handle.

FABRICATION

The following materials are readily available and are required in addition to those previously listed:

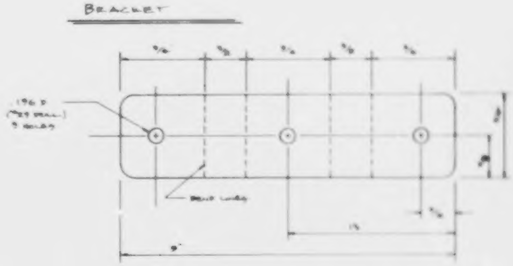
1/16" sheet aluminum
6/32" x 3/4" flat head machine screw (1)
6/32" x 3/8" flat head machine screw (2)
6/32" lock nut (1)
3/16" nylon washer, 1/2" OD (2)
#6 external tooth lock washer (1)
#6 countersunk finishing washer (3)

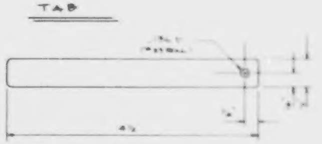
The following tools are necessary in addition to those previously listed:

#29 drill bit
#36 drill bit
6/32" tap
5/16" open end wrench
scratch awl
center punch

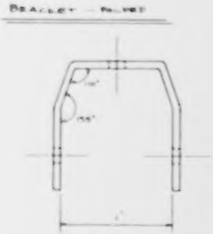
1 - Cut a 7/8" length of delrin hollow rod and drill out center as previously described.

2 - Using an awl, lay out the patterns for the bracket and tab on the 1/16" aluminum. Note: The width of the tab is determined by the width of the appliance slot. The tab pattern shown is for a 1/2" inch slot. Center punch and drill holes with a #29 bit. Cut out the two pieces on a band saw and file corners and edges smooth.





3 - Using a vice, or a sheet metal bending brake if available, start from the inside and bend the bracket on each of the fold lines to form the U-shape. Note: If precise bending is unattainable, 1/8" Kydex plastic may be substituted to form the bracket without changing



any pattern dimensions. The Kydex bracket would be formed using a heat gun.

4 - With the delrin secured horizontally in a vice, use the center punch to mark a location midpoint between the two cut ends. Using a #29 bit, drill straight through to the center of the rod.

5 - Insert one 6/32' x 3/4" screw through the top hole in the bracket and through the hole drilled in the delrin. With the bracket squarely positioned such that a 1/4" space exists between it and the delrin mark the two side holes. This 1/4" space is necessary to insert a 5/16" open end wrench for adjustment.

6 - Center punch and then drill each of the side holes with the #36 bit. These side holes should be oriented perpendicular to the top holes. Use a 6/32" tap to thread the side holes only.

7 - To assemble, insert a 6/32" x 3/4" screw through a finishing washer, a nylon washer, the aluminum tab, a second nylon washer and the top hole in the bracket. Fasten this screw to the bracket with a lock washer and lock nut. The bracket is now slipped over the delrin such that the end of the screw extends into the unthreaded hole. Line up the side holes and insert a 6/32' x 3/8" screw with a finishing washer through each.

8 - One aluminum collar is spread and slipped over the razor handle followed by the delrin sleeve and a second aluminum collar. The delrin sleeve can be set on the length of the handle to achieve the most functional position. For further adjustment the tab can be bent. Note: This adapted shaver is typically issued with a 5/16" open end wrench so the user may have the tension on the pivoting tab adjusted to specific needs.

CONCLUSION

The two versions of the Adapted Shaver design can enable an individual with a C5-6 level spinal cord injury to independently shave all facial areas. The modification of the shaver is external, easily transferable, durable and low-cost. The design can be duplicated using tools found in most rehabilitation engineering or occupational therapy departments.

SUPPLIERS:

. McMaster-Carr Supply Company
P.O. Box 4355
Chicago, Illinois 60680

(312) 833-0300

- Delrin hollow rod
  Item # 8627K62
- Aluminum shaft collars
  Item #6157K14
- 17/32" Drill
  Item #2931A45

. Central Steel and Wire Company
3000 W. 51st. Street
Chicago, Illinois 60680

(312) 471-3800

- 1/16" (.063) sheet aluminum
  Grade - 6061-T6

. Local hardware store

- Various fasteners

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REACHER WHICH PROVIDES LOW JOINT FORCES

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Knight, L. W., Phillips, M.

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ABSTRACT

Reachers are assistive devices which allow a person with hip, back and lower extremity limitations, to grasp objects outside his or her restricted range of motion. The emphasis at the Harrington Center has been to include the varying disabilities of people with arthritis into the design criteria of product design in the assistive devices area.

INTRODUCTION

Existing reachers extend the reach of users by the use of grippers on the end of a 20-30 inch beam. The results of this type of device are that the weight of the object at the end of the 20-30 inch moment arm tends to exert much higher joint reaction forces in the fingers, hand and wrist as compared to picking up the same weight object in the hand. See Fig. 1

In a typical unit there are three main sources of energy expenditure:

> The fingers of the hand in conjunction with the palm must counteract the torsion induced by the mass of the object and the moment arm to hold the reacher in the hand.
>
> The fingers must in addition add and modulate the amount of force necessary to hold the object and maintain that force until the object is placed in its desired location.
>
> The total moment arm plus the distance from the hand to the wrist must then be counteracted by muscles in the forearm to prevent torqueing the wrist into ulnar deviation.

Preliminary analyses of existing reachers, indicate that joint reaction forces at the wrist can be up to ten times the force of lifting an object without using the reachers.

CONCEPT DEVELOPMENT

Based upon these considerations and evaluations, it was decided to design a reacher which would reduce the forces in the hand and wrist . The concept was not to design to a highly specialized population, but to design a product flexible enough to be used by many people with varying degrees of disability. The underlying concept was that the device should only supplement the amount of energy that the user is unable to provide. If for example the user has sufficient grip strength, he should be able to make use of it with no penalty in performance. If however, the user lacks sufficient grip strength, the device should compensate for the lack of grip strength.

A concept was developed which would provide:

> An enlarged handle to reduce the amount of flexion of the fingers.
>
> A method of storing energy into a system which would spring closed upon actuation of a trigger.
>
> A reduced trigger movement which would reduce the necessary range of motion in the fingers
>
> Stabilization of the wrist by providing a forearm support.
>
> Stabilization of forearm rotation by lowering the center of gravity of the load on the end of the reacher.

PRELIMINARY TESTING

A non-mechanically functional soft model prototype was developed to test how the product would fit the user and what type of accessability problems would arise. The results of this preliminary testing were very useful in further understanding the types of problems associated with reachers.

RESULTS OF PRELIMINARY TESTING:

> Rheumatoid arthritis patients with hand involvment typically lose thumb and forefinger prehension which greatly reduces their capability to grasp handles.
>
> Hand involvement often includes drift of the fingers which further deteriorate under torque loading conditions of the fingers.
>
> Incorporation of a forearm brace can help reduce torsional forces across the wrist but does not by itself eliminate torsional loads across the wrist.
>
> The orientation of the moment arm was initially designed to be biased to picking things off the floor which compromised access to shelf heights.
>
> A stored energy / release system would present a problem of releasing the load and re-energizing the system.
>
> A stored energy system would need a feedback control to modulate the amount of gripping force needed to grasp light, heavy, durable or fragile objects.

Based on these results a second concept was developed which answered this criterion.

The idea of retaining a reacher handle to grasp was abandoned due to the limitations in hand involvement. Another forearm brace was added to the distal end of the forearm which captures and counter-balances the torque of the load and moment arm across the forearm. Having dispensed with the need for a handle to counteract torque in the hand, the handle evolved into a control rod to control forearm rotation. A thin rod can fit between the thumb and forefinger for non weight bearing control.

The axis of the moment arm was moved from the bottom of the grip to the top of the control rod and angled downward to maintain the lower center of gravity of the load. This configuration allowed more access to shelf heights.

A mechanical design concept was developed which utilized a pivot on the moment arm to allow the moment arm to cam downward when the load is engaged, this would tighten an internal cable, further tightening the grippers. As the load was applied to a surface, the arm would raise untensioning the cable, which would release the object.

A prototype of this concept was built. At rest, the moment arm hung in a downward position where the grippers closed against each other. To engage the load,the proximal end of the device was depressed, raising the moment arm which untensioned the cable and allowed the grippers to open. The grippers were then positioned around the load and the moment arm released to engage and tension the grippers. This provided a means to automatically modulate the amount of force being applied to the gripper. The heavier the object, the tighter the grippers would engage the load.

Most of the problems associated with this concept involved; targeting the object, the necessity of using two hands and the users expectation that an action of their part would release, rather than engage the object.

The targeting problem was related to the motion of the moment arm while trying to engage the load. To manipulate the gripper, the moment arm needed to be articulated, causing a shift in the relative orientation of the gripper and load. This necessitated the reorientation of the device back to the load site while maintaining the correct moment arm articulation.

Further development of the device provided a means of maintaining the moment arm in a straight configuration until the load is engaged. This is accomplished by springing the moment arm in an upward position and employing a separate cable tensioner. The user rotates the self locking tensioner by lever arm, which tensions the cable, closing the grippers around the load. This provides a device which is multi-modal in usage. If the user has reasonable hand function, he may choose to use the device in a single hand mode. If the user has hand involvement, he may choose to use the other hand to activate the tensioner. While this is a less direct approach, the product still allows the user with hand involvement to use the device. Once engaged, the load then cams the arm downward, further increasing the grip force on the object.

The moment arm was moved to align with the axis of the forearm to increase the targeting ability of the device and detail drawings of the internal mechanical components were developed to test the concept.

PROTOTYPE DEVELOPMENT

A mechanical prototype was developed to demonstrate the capabilities of this type of system. The prototype employs a pivoting 24.0 inch moment arm counterbalanced by a 0.625 inch moment arm which gives a 38.4 : 1.0 mechanical advantage ratio. A stainless steel cable connects the grippers through the moment arm to a take up spool housed in a frame. This spool is then linked to a ratcheted spindle to which an upper or lower lever arm can be inserted. This assembly is mounted to a horizontal bar which is mounted to distal and proximal supports.

The final detail to be solved on this prototype was to design and develop a high friction gripper which would, with minimal force, engage the object to be lifted enough to cam the moment arm downward. The existing products utilize a high friction material and a shape which accommodates an "average" shape. In many cases, the actual surface area in contact with the object is quite small necessitating relatively high force concentrations. This problem was broken down into two major subsets, choosing a material with a high coeficient of friction and applying the maximum surface area of the material to the surface of the object. Concepts were developed which explored the possibility of using, articulating prehensile, interlocking, deforming, adhesive and loop grippers. Load deforming high friction grippers seemed to present the best compromise between simplicity and performance. The prototype uses elastomomeric bands which are strung in tension across the gripper. The bands deform around and capture the object. This provides more surface contact between the gripper and the object. As the moment arm cams down, the object is compressed against the bands which compress against the gripper. See Fig. 2

The prototype was evaluated by occupational therapists at St. Lukes Medical Center.

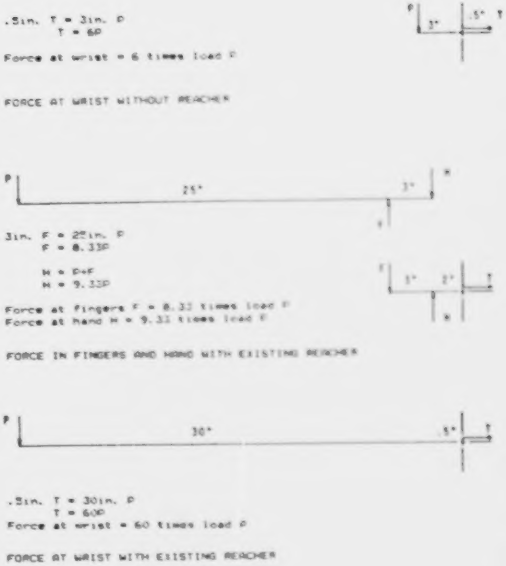
A lighter composite material prototype was further developed which incorporates better accessability into the forearm grip. The internal components were simplified by substituting Kevlar for the steel cable. The streamlined mechanism also permits the use of an expandable moment arm. See Fig.3

CONCLUSION

The new device provides for potential hand deformity, lack of range of motion, lack of strength, multi-modal usage and modulation of the gripping force. It requires only the amount of force necessary to bring the grippers into contact with the surface of the object. The device reduces the torsional forces on the wrist by the use of a highly accessable, self capturing, two part forearm brace which places the rotational axis of the moment arm on the forearm rather than the hand. Composite materials have been incorporated into the components.

ACKNOWLEGEMENTS:

The Harrington Arthritis Research Center would like to thank the Flinn Foundation for funding research in the assistive devices area.



.5in. T = 3in. P
T = 6P

Force at wrist = 6 times load P

FORCE AT WRIST WITHOUT REACHER

3in. F = 25in. P
F = 8.33P

H = P+F
H = 9.33P

Force at fingers F = 8.33 times load P
Force at hand H = 9.33 times load P

FORCE IN FINGERS AND HAND WITH EXISTING REACHER

.5in. T = 30in. P
T = 60P
Force at wrist = 60 times load P

FORCE AT WRIST WITH EXISTING REACHER

FIGURE 1

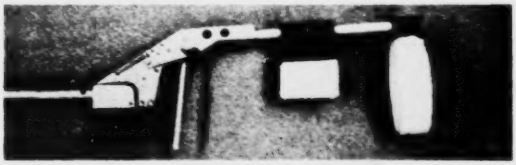


FIGURE 2

FIGURE 3

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DEVELOPMENT OF A PROTECTIVE HELMET FOR DISABLED PEOPLE

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ABSTRACT

The goal of this project was the development and testing of a helmet that will provide effective head and especially facial protection to people with a high risk of injury due to falls.
The helmet is a three-piece construction (anterior section, posterior section and chin cup) and comprised of a hard outer shell and soft inner liner. Both parts are industrially prefabricated. During assembly the orthotist achieves a custom fit by positioning the parts on the client's head. When the desired fit is achieved the parts are riveted together to create a single unit. A hinging mechanism facilitates donning and doffing.
The new device was evaluated from three perspectives: clinical, engineering and manufacturing. Results showed the helmet to provide effective protection and was well received by orthotists, caregivers and wearers.

INTRODUCTION

The neuromuscular disorders of certain people can cause them to experience frequent falls that potentially result in severe head and especially facial injuries. These injuries can produce damage to teeth and oral structures, excessive scarring, and may require lengthy hospital admission. Fear of injury can result in severe restrictions of the person's daily activities, thus preventing their development to full potential.

A new helmet has been developed, produced and assessed at the Hugh MacMillan Medical Centre which provides protection against such injuries. (see figure 1.)
At the outset, the criteria for a successful design were defined as:

a) a high degree of appropriate anatomical protection;
b) custom fit;
c) unobstructed vision;
d) good cosmesis;
e) comfort and light weight;
f) reduced heat build-up through cut-outs in the liner and helmet;
g) low cost.

HELMET DESIGN

The design is based on the concept of a hard outer shell with a soft inner liner. Both parts are industrially produced in quantity to reduce costs. The outer shell, made of high density polyethylene, is produced by rotational molding. The liner is compression-molded polyethylene foam. The shell is comprised of three sections: an anterior section, a posterior section and a chin cup. Three corresponding liner parts fit into the shell sections.

A hinging mechanism, one located on each

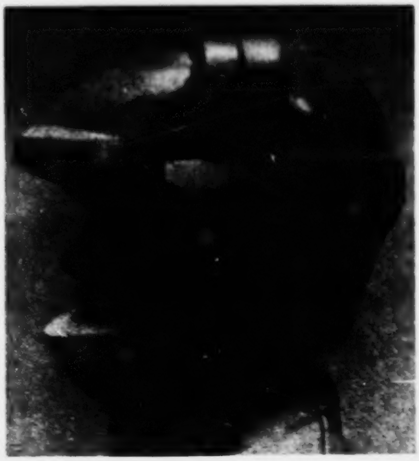

FIGURE 1: The Assembled Helmet

side of the helmet, performs three functions: to attach the anterior part to the posterior part; to permit the posterior part to pivot up with respect to the anterior for easy donning and doffing; to provide a fastening function which maintains the helmet on the head once it has been donned, and which unlocks to permit easy removal.

Each hinge mechanism is constructed of two parallel sheet metal 'straps' which are bent and riveted together at the top end and connected with a two-part Fixlock fastener at the other. This is the assembled hinge unit. One unit is riveted to each side of the shell in the space between the overlap of the anterior and posterior parts. One strap is riveted to the posterior part during a subassembly process. The other strap is attached to the anterior part during the fitting process.

It was determined that to fit people of all ages and head sizes the helmet would ultimately have to be available in three sizes. Since costs of development, tooling and production are high the medium size only has been developed for assessment at this stage. Each size will fit a range of head measurements. Generally, the medium size is intended to accommodate heads with circumferences between 500 and 570 mm.

FITTING PROCEDURE

The helmet is dispensed to the orthotics clinic as a subassembled, complete 'kit'. All parts have been trimmed, the liners inserted into the shell parts and the assembled hinge units mounted on the rear part of the shell.

During the fitting appointment, the helmet is fitted on the client's head and temporarily assembled. The client can then go home. The helmet is finished by the orthotist at a later time and mailed to the person. This procedure requires only one appointment for the client, and makes most efficient use of the orthotist's time.

During the fitting process three techniques are available to the orthotist to achieve the desired custom fit. Firstly, the three parts are adjusted on the client's head. The posterior part slides over the anterior part along the lateral aspect, permitting anterior-posterior length adjustment. The chin cup, too, can be positioned at varying angles and lengths. Once the desired fit is achieved, the parts are riveted together to produce a single-piece unit. Further customizing modifications are possible through trimming certain edges of the shell, for example the areas around the ears. The surfaces of these peripheral areas have been kept plain to allow for easy reshaping. A third modification technique is the optional addition of liner insert pads between the shell and liner to increase the snugness of fit in specific areas.

PROTECTIVE FEATURES

Effective protection is afforded through a number of features. A major factor is the custom fit which can be achieved. This ensures that the protection is located where it is needed and that it remains in place, especially in the event of a fall.

Secondly, the hard shell functions to distribute the force of an impact over a larger area and to prevent sharp objects from penetrating and injuring the head. It also determines the overall shape of the helmet. In exploiting this feature, the front part of the helmet (covering the forehead) projects out, as does the chin cup, to protect the face in the event of a fall. A horizontal rib across the posterior surface provides space for extra liner thickness over the occiput. The rear part is also contoured to 'tuck' under the occiput, which when coupled with a similar 'tuck' under the chin cup, helps to secure the helmet in place and resist unwanted removal. The shell is shaped to ensure unobstructed vision and the ears are left uncovered to facilitate hearing. The top section of the shell, where little protection is needed, is left completely open to reduce weight and to promote ventilation.

The liner serves to absorb the energy of impact. It also interfaces the contours of the shell with the contours of the head to produce the intimate fit. The liner is also designed to increase ventilation. Liner parts are moulded so that only raised pads touch the head, with wide channels running in between to act as conduits for air circulation.

ASSESSMENT

To evaluate how successfully the new design met the criteria it was examined from three perspectives:

(i) Clinical Evaluation

Two orthotists at the Centre fitted a total of ten people with the new helmet. These people wore the helmet exclusively for a two month period. At the end of that time they returned to the Orthotics Department for assessment by the orthotists and caregivers.

(ii) Engineering Testing

The impact absorption properties of the helmet were tested at a biomechanics testing laboratory using the Helmet Drop Test. Designed at Wayne State University it determines the ability of a helmet to decelerate the brain and prevent concussion.

(iii) Manufacturing Analysis
Costs to produce and dispense the ten helmets in the context of the development stage were determined. An assessment of both the added costs and savings in the transfer of technology to production was made.

Results of the evaluations showed the new design to have effectively met the design requirements. Some minor modifications were also indicated to optimize it.

(i) Clinical trials and impact testing both showed the helmet to perform its primary function, that of providing effective protection. While all the clients had histories of frequent falls and injuries, caregivers recorded only two minor incidents and commented on the helmet's observed protective performance when falls did occur. During the impact testing the helmet performed within the acceptable range of safety at the maximum height tested (1.07 m.)
(ii) A custom fit implies a secure fit with protection provided in the right areas without compromising vision or comfort. The ten children, whose head circumferences ranged between 500 mm. and 565 mm., were successfully fitted. Four were at the small end of the range and orthotists felt a smaller size of helmet would have been easier to fit. It was also recommended that an educational manual be prepared to explain the fitting objectives and assembly proceedures to orthotists.
(iii) The shape of the helmet around the eyes is such that visibility was never a problem. Locating the helmet correctly around the face is the first step in fitting.
(iv) Generally the appearance of the helmet was liked and certainly preferred over most other alternatives. Both shell and liner can be produced in a variety of colours which is desirable. All corners and edges of the shell will be more generously radiused to soften the look.
(v) The helmet was assessed to be comfortable by all the wearers and caregivers. Seven of the children were minimally or non-communicative so their willingness to wear the helmet was used as an indicator of their comfort and acceptance of the device. A highly valued feature, by all caregivers, was the functioning of the hinge mechanism. It made donning and doffing the helmet an easy and fast task which they felt contributed to its acceptance. The weight is about 1 lb. which is comparable to or less than most other helmets.
(vi) Although measures were taken in the designing of the helmet to provide ventilation it was felt that the helmet, because of the area covered, was still warm to wear. The incorporation of ventilation slits in the shell will be investigated.
(vii) The final costs in a production setting are not established. However the prefabrication of parts requires only the orthotist's assembly time to produce a custom helmet. Hidden savings include those to parents who must make only one clinic visit (taking time off from work), to institutions (which pay extra staff to accompany residents to the clinic) and to the medical system through the prevention of costly injuries. An additional advantage to this new design is the potential for dispensing custom-fitting helmets from clinics which are remote or not well equipped.

The provision of an effective helmet - clearly increased the mobility and independence of several of the wearers. One fellow was given added responsibility at his sheltered workshop once he had his helmet. Another girl was allowed to participate in 'Play Day' at her school. A third child was restricted to a stroller when outside unless she wore her helmet.

FUTURE WORK

The focus of further efforts will be on the development of two more sizes, incorporating the modifications indicated from the initial work.

ACKNOWLEDGEMENTS

We would like to thank the Design Department at Cooper Canada who shared their experience and knowledge of helmets and their testing facilities.

A DESIGN FOR THE BACK OF SEATED POSITIONING ORTHOSES THAT CONTROLS PELVIC POSITIONING AND INCREASES HEAD CONTROL

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ABSTRACT

The most difficult problems encountered in dealing with the seated positioning needs of disabled individuals are pelvic stabilization and head control/position. When analyzing these symptoms from a biomechanical and neurodevelopmental perspective, the etiology of many head control/position problems can be traced to lack of pelvic stabilization and/or inappropriate pelvic positioning.

The Bi-Angular Back design (Figure 1) described in this paper addresses these two issues simultaneously.

BACKGROUND

Head Control/Position

To determine the etiology of head control problems, one has to look lower on the anatomy at the normal curvature, or lack of normal curvature, in the spine; and at the position of the pelvis. When the curves of the spine are "abnormal", the resulting head position will be "abnormal". To approximate a normal curvature in the spine one must be able to stabilize the pelvis in the desired position, and recreate the normal lumbar lordosis, thoracic kyphosis, and cervical lordosis, and thereby balance the head over the pelvis.

Pelvic Position/Stabilization

Often, when seating the child with cerebral palsy and other diagnoses, one is faced with problems of increased hip extensor activity, resulting in "pelvic thrust" or a posterior pelvic tilt. A commonly accepted approach to dealing with this problem is to attempt to flex the hip joint past 90 degrees by decreasing the seat to back angle of the seated positioning orthosis; or by using a "rolled" seat that has the effect of decreasing the seat-to-back angle.

Repeatedly, this concept is often used, or misused, without taking into consideration:

- limitations in passive range of motion at the hip joint
- the ability of the seated positioning components to insure pelvic position
- the relationship of the angle of the anatomical hip joint to the mechanical angle between the seat and back of the seated positioning orthosis
- potential decrease in upper extremity function due to excessive rearward tilt forcing the musculature to function against gravity.

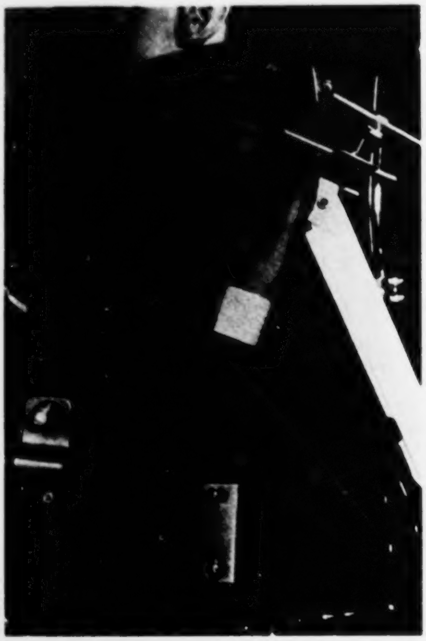

Figure 1 - Bi-Angular Back (BAB), with scapular relief, used on a Tiltable Seated Positioning Orthosis (TSPO) designed by the Dept. of Rehab. Engineering, U. of Wisconsin-Madison

Limitations in PROM at the Hip Joint

In the case of limitations in the passive range of motion at the hip joint decreasing the seat-to-back angle forces the pelvis into further deformity by increasing the posterior tilt of the pelvis. This may have the effect of decreasing the mechanical advantage of the hip extensor muscles at the expense of creating potentially rigid or even "fixed" deformities of the spine,; and often at the expense of head control/position. When the pelvis is forced to tilt posteriorly the entire spine is affected. Normal lordosis is lost, thoracic kyphosis is increased, cervical lordosis is decreased, and the neck and head fall into flexion. If the patient is able to lift their head, then the typical "stacking" pattern may be manifest.

Appropiate Pelvic Stabilization

If one is not careful to stabilize the pelvis, the body will slide forward, or push forward during an "extensor thrust", and end up with the same result as when there is insufficient range of motion at the hip joint. Often times in individuals with increased hip extensor activity a seat belt is not adequate to stabilize the pelvis, even when securely tightened and attached with a correct line of pull, i.e., below the A.S.I.S. This is often due to the subjective nature of how tight a securely fastened seat belt should be. In these cases, a Subasis Bar has been effective in securing the pelvis and preventing forward thrusting at the hips. It also is useful to reduce and/or prevent the progression of rotational deformities at the pelvis.

Mechanical vs. Anatomic Angles

Another important factor to consider in designing a seated positioning system is that even when the mechanical seat-to-back angle is 90 degrees, the anatomic hip angle, even with the pelvis properly secured, may be greater than 90 degrees. In a study by Nwaobi, results showed that "related hip flexion angle and the angle between the backrest and the seat are not equal in most seating positions". In this study, when the seat-to-back angle was 90 degrees or less, the hip flexion angle was always greater than the seat-to-back angle. This was true for both normal and cerebral palsied subjects.

These, and other similar scenarios lead us to believe that, in general, problems with head control/position may must be addressed most effectively by appropriate pelvic position.

DESIGN

The Bi-Angular Back (BAB) design incorporates a two section back. The lower section is attached to the seating surface of the seated positioning orthosis at an angle of approximately 75 to 85 degrees (as allowed by the clients passive range of motion). The lower back section extends superiorly to the level of the posterior superior iliac spines (PSIS). The lower back is rigidly attached to the upper back section at an angle that complements the seat-to-back angle plus 5 degrees. By inclining the upper back posteriorly, one can assure that the anterior/posterior midline of the head is set just posterior to the midline of the pelvis.

Figure 2 - Subasis Bar with mounting brackets

Figure 3 - Stabilizers positioned to retract and depress shoulders

A seat belt or Subasis Bar (Figure 2) positioned to apply a posterior/inferior force, inferior to the anterior superior iliac spine (ASIS), must be used as a counter force to the anteriorly directed force applied to the PSIS. The effect of this design is to reduce hip extensor "tone" or "thrusting" by "putting the hip extensor muscles on stretch": or more simply stated, decreasing the mechanical advantage of the hip extensor muscles. From a clinical perspective, the stability afforded by this design interrupts pathologic hip extensor patterns and allows the patient to use back extensor musculature for increased function and stability.

The BAB design avoids the problem of lost head control/position caused by usual attempts to reduce hip extensor activity by decreasing seat-to-back angle alone. The fact that the upper section of the back is set at an angle to complement the decreased seat-to-back angle, allows the lumbar spine to extend and place the head in a balanced position over the pelvis. The need for anterior head support (which is at best cumbersome and cosmetically unacceptable, and at worst useless), is virtually eliminated. A posterior head support applying forces primarily in the area of the occiput (in a superior/anterior direction), is extremely effective in maintaining optimal head control/position.

Unless the client has sufficient trunk extensors, a force applied posteriorly in the upper thoracic region is also necessary. A properly positioned anterior thoracic vest or shoulder stabilizers (Figure 3) will also accomplish this task. The BAB design reduces the amount of posterior directed force that needs to be generated by these components by appropriate positioning of the upper torso and interruption of pathologic tone patterns. One must be sure that there is sufficient room for the scapulae and that they are not simply pushed into the padding of the upper back. A relief may need to be cut into the back padding at a level just below the inferior angle of the scapulae and extending superiorly to the top of the back (Figure 1).

CONCLUSION

Using a Bi-Angular Back (BAB) design, appropriate positioning of the pelvis and alignment of the spine is achieved. The normal complimentary curves of the spine are restored and the head is re-aligned over the pelvis.

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EXTENDING AN IDEA: AN ARM AND LEG EXERCISER FOR YOUNG PHYSICALLY DISABLED CHILDREN

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ABSTRACT

Two new accessories for a dynamic standing device now allow reciprocal leg and arm movement within the stationary desk frame. The design of these exerciser components and their use with children in the positioner desk are described.

BACKGROUND

We developed the positioner desk as an alternative positioning device to give young children with a variety of disabilities the opportunity for controlled lower extremity weightbearing and independent movement within a prescribed range.[1, 2] Its boxlike frame holds a set of interchangeable components which includes a seat, tray, footplate, knee block, and trunk support. The slots on the sides of the box and the mounting hardware for each component allow a great range of adjustment with the child seated in it. This feature lets us look at the effects of subtle changes in the position or angle of the supports on the child's muscle tone and movement patterns and makes it easier to find the exact position in which the child's abnormal reflex patterns are inhibited and more normal movement patterns are facilitated. The forward tilting seat and the freedom of movement allowed between the supports have helped a number of children develop not only greater physical skill in coming to stand and sitting back down again, but greater confidence in their independent ability to practice the skills promoted in therapy sessions.

The development of an exerciser that would complement and expand the uses of the desk evolved from our observations of one seven year old child who had used the desk for four years with great success. Her motivation and that of her parents and physical therapist encouraged us to explore ways of challenging her further.

DESCRIPTION OF THE PROJECT

The idea for the design of the exerciser began with our experience with cross country skiing. In ideal ski conditions, gliding smoothly on fresh powder, the motions of cross country skiing seem easier than walking. Less effort is required to keep the legs separated while moving in a gentle reciprocal pattern when skiing in pre-made tracks. In addition, ski poles offer help for balance and soft powdery snow cushions a fall. Thus it was a modified skiing motion that we set out to imitate in the design of the exerciser.

There are a number of commercial cross country ski exercise machines available, and we spent some time studying these designs and even was able to use one machine for a short time on a trial basis. The machines offer an excellent aerobic workout and simulate the ski motion quite well, but their design could not be applied directly to an exerciser that would function as a removeable accessory to the positioner desk. Keeping in mind an overall desire for a simple, inexpensive mechanism that would be attractive and "user-friendly" to a young child, we decided to use roller skates for the leg exerciser. The brightly colored plastic version we tried certainly met our criteria for a product that would be attractive to a child, and, at $12 a pair, we were purchasing one item that incorporated a built-in shoeholder with the rolling mechanism. This application of an inexpensive commercial product spared us the research and design time that would have been required to build a sliding shoeholder, and gave us just the type of "fun" appearance we were seeking. A series of four 2½-inch nylon pulleys with plastic blocks to guide the nylon cable connecting the skates were a simple but effective solution. The pulleys were mounted at the corners of a removeable surface, with two mounted in slots to allow adjustment of the cable tension. This provided some variation in lateral movement of the feet as they moved back and forth and allowed each heel to rise during the "push-off" phase of the gait pattern. A knob and block on a bolt could be tightened to capture the cable and lock the skates into position so the desk could remain functional for its original purpose. The skates could be locked either with the legs in a symmetrical position or with either leg forward for a different challenge in coming to a standing position.

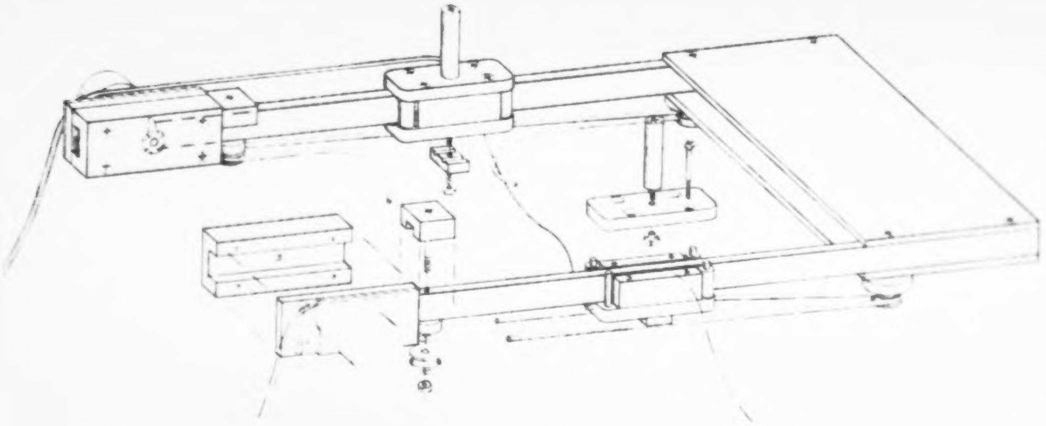

Figure 2. Construction of the arm exerciser.

The arm exerciser went through a number of prototypes before an effective model was developed. The first model used two hand pieces which slid back and forth on lengths of square tubing, mounted to the desk on locking angle-adjustable brackets. This system had the advantage of extending the range of the arm exerciser from the flat position of the "ski motion" to any angle up to vertical for range of motion exercises. Difficulties emerged with the sliding hand pieces, which were effective when pushed or pulled in a straight line, but tended to jam with the uneven twisting motions that the children's abnormal movement patterns induced as they attempted to use the mechanism. Another designer suggested using rectangular tubing with the long side on the vertical, giving an increased bearing surface to compensate for the lateral forces on the hand pieces as they moved back and forth along the tubing. We used standard 1-inch nylon spaces over ¼-inch stainless steel rod for the bearing surface against the rectangular tubing and the same low-cost nylon cable and pulleys (sliding door hardware found at a local building supply vendor) to create the reciprocal motion. We also discovered that we could change from a reciprocal to a symmetrical motion, depending on which of the two passing cables the right side hand piece was connected to underneath, creating another option for the use of the exerciser for strengthening weak muscles and extending active and passive range of motion.

CLINICAL RESULTS

Case 1: Amy's performance with her positioner desk was our initial inspiration. Both her parents and her physical therapist credited the desk with helping her develop better trunk balance and righting reactions, more strength in her legs, confidence in her ability to stand and move without falling, and interest in developing these skills even further. It made great sense to us to use the desk as the basis for an exercise machine when her therapist asked for a device to help Amy develop her ambulation skills and increase the range of motion in her arms. We knew that we could trust the family to work through all the perils and pitfalls of prototype development with us because of our relationship with them in the past. Our concerns about how Amy would cope with the moving footpieces without losing her balance melted away when we happened to notice her confidence in the desk one day while we were all talking. Amy spent most of that time not only standing up and sitting down independently, but pulling on the tray to change its angle, leaning over to one side to pick up something she had dropped, and shifting her weight as unconsciously as any child bored with the conversation of the adults around her. She had managed to learn how to dissociate her movements, rotate her trunk, cocontract her hip and leg muscles to support her while doing things with her upper body. It was obvious that she was ready for a bigger challenge.

Amy's first session in the exerciser desk was strenuous for her. She quickly learned to move her feet reciprocally, both sitting down and standing up, and her physical therapist was delighted to palpate the muscle contractions in her buttocks and thighs. Using the arm components was much more difficult, however. This required sustaining her grasp with both hands, not only her "good" hand but her "bad" one as well, and she was at first unable to move the grips reciprocally without letting go of one or the other. We adjusted the mechanism so the pieces moved symmetrically and she was more successful. Her right hand became the prime mover, and the left pretty much went along for the ride, but even the passive range of motion provided by this was beneficial to her, as her therapist reported that she had been losing passive range over the past year or so. Changing the angle of the arm piece provided exercise throughout quite a range, stretching out in front and reaching up over her head.

Amy's excitement over having her own exercise device was largely because of her family's fitness activities. Both her parents work hard at staying in shape, and physical activities play a large part in the family's routine. Amy at last had something she could work at without anyone's assistance, a point of pride for the big sister of the family, and she enjoyed the attention and envy of her and her sisters' friends when they came over to see her "cross country ski machine".

Amy underwent extensive surgery this winter with the goal of aligning her hips and allowing more normal leg movement. We are hoping that the exerciser desk can be an integral part of her recovery process, providing her with the opportunity to regain her strength and range of motion with more independence and responsibility for her own therapy and a sense of enjoyment and accomplishment.

Case 2: Megan was 3½ years old and had been using her positioner desk for less than a year before we converted it to an exerciser. We decided to start her off with just the leg components when she had trouble using the arm exerciser because of her spasticity. We also didn't know her as well as Amy and weren't sure how well she would respond to the exercise task, being so much younger and less verbal. After six months of use, however, she had made a great deal of progress in all areas of functioning and very proudly showed us how she could roar along on her skates. She obviously enjoyed it so we added the arm unit. Like Amy, Megan showed better skill with one hand than the other but was able to hold on even with her left hand after a little practice. We are anxiously awaiting our next followup visit to see how well she progresses.

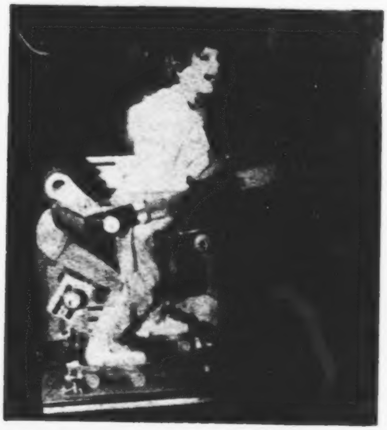

Figure 3. Megan working out on her exerciser.

Case 3: Nate has been one of our favorite positioner desk users since we first saw him at two years of age, so it was with great disappointment that we found that the exerciser components were not appropriate for him. His spasticity is more marked than Amy's or Megan's and his potential for even part-time assisted ambulation much more limited. We were hoping that the roller skates would give him some sense of independent mobility in the desk but the effort required to move one foot forward invariably increased his muscle tone in his other leg so that he could not relax it enough to let it move back reciprocally. This was also the case with the arm exerciser, even when it was set up to move symmetrically. While we hope he may be able to use the exerciser at some point, we realize that his power chair and the custom seating system we built for him will play a much larger role in his development.

CONCLUSION

Our original goal of developing an exerciser accessory for the positioner desk was met with the two prototype designs we have described. Additional work on the mechanism could lead to a more refined product, though it is unclear at present how widely it can be applied. We have learned that the use of this type of equipment is dependent on a supportive family setting, where there is a willingness to deal with the complications of attaching and removing the accessories and encouraging their use.

We believe that the great strides in developing more functional equipment for mobility and seating should be matched by gains in designing equipment that enables disabled people to reach their full physical potential. The new emphasis on fitness with stationary bicycles and rowing machines in so many American homes challenges us to provide more opportunities for people with disabilities to develop their own programs of therapeutic exercise. We would be interested in hearing from others who are working in this direction.

ACKNOWLEDGEMENTS

This work was supported by the Department of Mental Health, Commonwealth of Massachusetts. Special thanks to the Adaptive Design Services staff, to Wendell Oppewall, Director, and to Carl Johnson, Environmental Designer, for his ideas and assistance with the arm exerciser mechanism and its illustration in Figure 2.

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CRUTCHES: LOW TECH OR HIGH INTEREST?

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ABSTRACT

People use crutches on a temporary or long-term basis as an assistive device for independent living. The selection, care, and use of crutches and their constituent parts is a key to safety, comfort, and endurance. The chief problem areas for new crutch users are inefficient hand position and slipping foam hand-hold covers. Pincer grasp of thumb and forefinger on the crutch upright and fixation of foam covers are recommended solutions. The chief problem areas for experienced crutch users are lack of awareness of the needs of crutch-users by architects, builders, and the general public; and low durability of crutch tips. Improvements in awareness, materials, design, and instruction are needed for both new and experienced crutch-users.

INTRODUCTION

While the topic of crutches can be considered "low tech", i.e. non-electronic, there is a high degree of interest in crutches by the estimated two million persons in the U.S.A. who are temporary or long-term crutch-users. Figure 1 illustrates both types of crutch-users. The man is moving slowly, due to his being a new crutch-user. The woman is moving more rapidly, and is clearly an experienced crutch-user. Note the hand grip she is using, in contrast to the grip used by the novice.

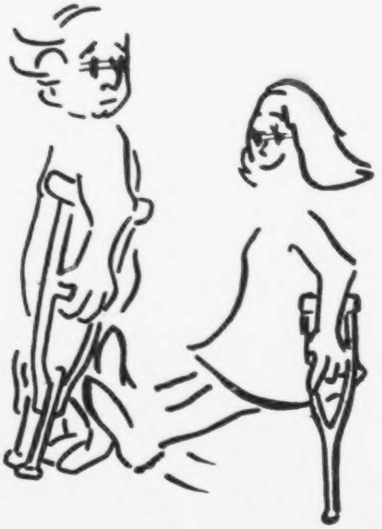

Figure 1: New and experienced crutch users

BACKGROUND

People use crutches on a temporary or long-term basis as an assistive device for independent living. As extensions of one's arms, crutches enable a person to overcome gravity, stand upright, maintain one's balance, and move in a horizontal or vertical plane. The information in this paper is aimed at three distinct populations: consumers, producers, and practitioners. The consumers fall into two groups, new and experienced crutch users. The producers include designers, manufacturers, and repairers of crutches. The practitioners include prescribers and teachers of the use of crutches.

The primary consumer target population is the large group, estimated at over a hundred thousand annually, of first-time, temporary users of crutches. These persons have become crutch-users through an accidental injury to a leg, knee, ankle, or foot. Many temporary crutch-users are athletes. They have hopes of getting off their new crutches as soom as possible. They have no desire to become experienced, long-term users of crutches. They are so inexperienced that they don't know what questions to ask the person who hands them their first pair of crutches. They are usually in pain or discomfort from whatever condition led to their being given crutches. In the past, they may have borrowed a friend's crutches to gallop around on, with their two good legs, knees, ankles, and feet. That past experience now interferes with their learning how to walk with their new crutches. In short, a new temporary crutch-user is poorly prepared to use his or her new crutches.

The secondary consumer target population of crutch-users is the large group, estimated to be in the millions, of person who use one or two crutches on a long term or permanent basis (For example, the woman in Figure 1.) Permanent users typically are looking for improvements in the design of crutches and crutch accessories, such as crutch tips and hand-holds.

METHODS

Data were collected by reviewing literature and interviewing persons using crutches. The literature review included information sources such as NARIC and the indices of Applied Science and Technology, Rehabilitation, and Nursing. Interviews were conducted with over 100 persons at cast rooms and in hospital/clinic corridors (temporary users) and 50 persons attending Post-Polio Conferences (long-term users).

RESULTS

The literature review demonstrated the lack of attention given to crutches, crutch accessories, and users of crutches in the past twenty years. A total of 40 references were located through the three sources cited in the Methods section of this paper. None mentioned the importance of the hand-hold of the crutch and the position of the fingers in gripping the hand-hold. Little research was reported on any aspect of crutches and crutch-users. Bennett and Murphy (1977) performed the only research on crutch-tips, paradoxically finding that old, worn, hard crutch tips performed as well as new tips in their tests of slippage on wet, soapy tile floors and on ice.

New crutch-users reported being asked their height and given their new crutches without any instruction about the care and use of crutches. Nearly all the new users reported sore hands, wrists, and arms, primarily due to the necessity of squeezing the slipping foam hand-hold covers. All the new users were using the inefficient "suitcase handle" grip with their fingers curled around the hand-hold and their thumbs in opposition, also curled around the hand-hold. All reported discomfort and a feeling of unwieldiness in using their new crutches. Some were leaning on the axillary support (underarm bar) at the top of the crutch, and had suffered "crutch paralysis". None had had any instruction about the ordinary care needed to keep their crutches in good operating condition, such as routine tightening of wing nuts and inspection of crutch tips for wear.

Long-term users of crutches reported a different set of circumstances. Each person had developed a style of his or her own, depending largely on the residual muscle power available to use crutches. Although each person had adapted to using crutches, there were several universal suggestions for improvement of crutches, crutch acessories, and the environments in which crutches are used. No long-term user had slipping hand-hold covers. About one-fourth were already using a pincer grasp. Over one-half had never thought about a different grasp, and immediately switched to a pincer grasp. Of the remainder, a few persons tried a pincer grasp and reported some difficulty in switching their method of grasp. Others were using short, fore-arm crutches with a forward-pointing hand hold, which obviated the possibility of a pincer grasp.

Improvements needed for crutches included in the areas of durability of materials, non-destructive testing to ascertain any incipient weaknesses (preventive maintenance), and durability of crutch tips. Particularly exasperating were crutch tips without metal inserts to prevent the bottom of the crutch from boring a hole in the tip.

Long-term crutch-users reported their experiences in a variety of living, working, studying, and traveling environments. Among their complaints were the lack of hand-rails, slippery walking surfaces, too-narrow corridors, protruding room partition and furniture feet, elevator doors which closed too rapidly, and having to use freight elevators when escalators were the only other means of ascending or descending in multi-story buildings. In addition, members of the general public appeared to be oblivious to the needs of crutch-users for space in which to move and balance oneself.

CONCLUSIONS

The selection, care, and use of crutches and their constituent parts is a key to safety, comfort, and endurance.

Increased awareness by architects and the general public of the needs of crutch-users is required to enable both temporary and long-term users of crutches to become safely independent in daily mobility.

Improvements in the hand-holds and durability of crutch tips are needed to facilitate the safety, comfort, and endurance of crutch-users.

Self-instructional videotapes in emergency and cast rooms are recommended to prevent second injuries to new crutch-users. Such videotapes should have sound tracks in several languages and should also be 'signed' for hearing-impaired persons. An illustrated pamphlet should be given to each new crutch-user. The practice of providing slipping foam grips over the hand-holds should be discontinued. Any coverings of hand-holds must be firmly affixed to the hand-holds. New crutch-users should be encouraged to use a pincer grasp (or pistol grip) with thumb and forefinger on the upright of the crutch.

While the needs of new crutch-users and long-term crutch-users vary, both types of crutch-users require safe and comfortable crutches as well as assistance from the environment, and other people in order to attain and maintain their independence, health and good nature.

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ASSESSMENT OF LIGHT WEIGHT TWISTER TORSION CABLE BRACES AND CANES ON ONE YOUNGSTER

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ABSTRACT

The design and fitting of a light weight twister torsion cable and a tripod composite cane on one subject is discussed. The designs of the composite braces and the tripod canes are presented. These systems have advantages over the traditional designs in that they reduced calories expended and heart rate rise significantly during walking trials when compared to the heavier metal braces and quad canes. The relative merit of using lighter weight materials in cable braces and canes in youngsters is supported.

INTRODUCTION

Braces and other external appliances are used to provide support to a body part, to limit activity, to prevent or correct deformity or, in some cases, to encourage activity.

Decreasing the weight of the external device can be advantageous in enhancing mobility and reducing energy expenditure during functional activities.

A three-year-eight-month old boy with femoral hypoplasia using metal quad canes and metal torsion cable braces to control internal tibial torsion provided us with an opportunity to determine, from a physiological standpoint, the effect of lighter braces and canes.

METHOD

At the time of the first test the youngster was a three-year-and-eight-month old child. His bodyweight was 13.6 kg. Combined with the metal canes and braces he was using, he weighed 15.4 kg. Twelve percent of total mass was external supports. At his third and final test he had grown to 14.8 kg. Combined with the composite canes and braces he weighed 15.2 kg. Using the lighter weight external supports, only three percent of his total mass was external supports.

The subject was physiologically measured for heart rate by an electrocardiogram. Caloric expenditure while ambulating a measured 50 foot course was determined. He was tested 6 times with a one minute standing test between trials.

Canes were created from graphite and fiber glass tubing. The base was reduced from a quad cane to a tripod base for additional weight reduction. The weight of the tripod composite canes was .22% of the weight of the metal quad canes.

The lighter weight braces were constructed from stock components while other components were custom fabricated utilizing graphite composites.

Stock components consisted of the 10 mm plastic torsion elements as manufactured by IPOS Luneburg and supplied by IPOS USA in Lewiston, NY. These plastic torsion elements are lightweight and unbreakable. They require no covering sheath and will twist either to the right or left. They are flesh tone, and are very flexible. They also come in four different diameters, 8mm, 10mm, 12mm, and 16mm. They have some disadvantages: (1) they darken with time (although this does not affect their function) and (b) they are more costly than typical metal cables. While IPOS^{R} manufactures the hip joints, ankle joints and stirrups compatable with these torsion cables, they are stainless steel and it was felt that custom fabrication of these components from carbon fiber composites would significantly lighten the entire system.

The lighter graphite hip joints, ankle joints and stirrups are fabricated from pre impregnated bi-directional woven carbon fiber cloth (8 harness). These pre impregnated materials used either a 250 degree (F) cure or a 350 degree (F) cure epoxy system.* Stirrups and hip connectors were fabricated on aluminum molds and pressure cured in an oven. Post and finish these parts. In addition, appropriate holes were inserted at machining operations occurred subsequent to final cure in order to shape this time for mounting and joint axis. A second series of molds allowed threaded holes to be molded into the part during the initial curing process, thus eliminating the post cure drilling.

Clevis joints for hip and ankle were fabricated from prefabricated carbon/epoxy plating (5/64" thick). Strips of approximately 5/8" in width were cut from the plating and "sandwiched" together to form the clevis.

Cylindrical "sockets" about 2" in length were fabricated by filament winding unidirectional fiber around a 10mm plastic rod. A two component epoxy resin system was used in this case rather than a pre impregnated one since oven curing would melt the plastic mandrel. A plastic mandrel was used because it was easier to remove after curing. Other cylindrical sockets were made utilizing a two component acrylic resin system which seemed to be adequate for the job. The acrylic "tubes" were a bit heavier and thicker than the epoxy ones, however. A metal mandrel and pre impregnated system was attempted. However, the mandrel proved to be too difficult to remove after curing. Once the "tubes" were fabricated, a slot was cut through one end of the tube and the clevis was inserted, bonded with epoxy and wound with unidirectional carbon fiber. Chicago screws were used as axis bearings.

This child's femurs are in considerable abduction at all times. This required an "abduction" adaptor to correctly position the hip stirrups and joints. This was essentially accomplished with an aluminum wedge mounted to the pelvic band onto which the hip stirrups were attached.

The pelvic band was typical -- consisting of 1½ inch wide aluminum, padded with Spenco™ and covered with leather. Straps were fabricated from leather lined double thick dacron webbing.

This child's left leg was 2 inches shorter than his right leg. Because of this it was necessary to provide a 2 inch build-up on his left shoe. Various materials are utilized in orthotics to fabricate such shoe lifts; most common is crepe rubber. This was true in this case, i.e. this child was wearing 2 inches of rubber on the bottom of his shoe. Although this is one of the most durable materials for this purpose, it is also the heaviest. Balsa wood has been used for this application but is not as durable and usually looks best when upholstered with leather. Obviously, this isn't the best material for an active 4 year old. A high density polyethylene lightweight foam dense enough to bear his weight without compressing was used. While this 12 pound density foam may be sufficient for this child, higher densities may be necessary for larger children or adults.

Three sets of observations were made on the youngster to evaluate the impact of the exchange of his mtal canes and braces for composite canes and braces. The first observation took place before he received the composite items when he was 3 years and 8 months of age. The second observation took place two months later, after the youngster had time to receive and get accustomed to the new canes and braces. A third observation took place five months later.

Since heart rate is an indicator of energy expenditure and metabolic stress, a single channel EKG was utilized to monitor the subject's heart rate response to a standardized exercise task. For this task, a 50 foot course, over a tile surface, was laid out and the subject was instructed to walk this distance as quickly as possible. The time required for this walk was recorded in seconds. A one minute recovery period was required between the walking tasks. A total of 6 walking trials were completed. A Cal-Trak™, which records the acceleration of body mass and converts it to calories expended was employed to assess the effort of the walking task.

DISCUSSION:

The subject took an average of 79.6 seconds to complete the 50 foot course during the 1st follow-up, representing an increase of 3.1 seconds over the initial visit. During the first follow-up visit the subject was easily distracted, stopped frequently in spite of promptings, and had to be repeatedly encouraged to complete the task. The range of times (70.2 to 85.5 seconds) and the standard deviation for the times (+/- 5.2 sec.) indicate that the lighter devices were efficacious. For example, his average time (6 trials) to walk the 50 feet was 12.9% faster with the graphite than with the metal (66.6 sec. versus 76.5 sec.). His heart rate response was 71.6% less with the composite devices than with the metal. With metal devices his heart rate rose 29.2 beats per minute between the start and the walk (120.0 to 149.2 bpm). In composites, his rate only rose 8.3 bpm between the start and the finish of the walk (123.2 to 131.5 bpm) on the average.

This brief pilot study indicates that more research is needed. This future research should include observations, better control of external distractions, the utilization of video taping procedures and biomechanical analysis, as well as the use of telemetry for monitoring the EKG's.

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Resting Splint for Acute Neurologically Damaged Patients With Hypertonic Gastroc-soleus Muscle Groups

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ABSTRACT

This article discusses the needs and proposes a solution for preventing and/or reducing the tightening of the ankle plantarflexors and supinators during the acute phase of central nervous system (CNS) disorder. Many splints are currently on the market, however, most do not accommodate the sensitive reflex activity of the neurological foot.

INTRODUCTION

A variety of lesions of the CNS can produce spasticity. Some patients, usually the severe cases, develop strong spasticity very soon, that is within a few days. The excessive contraction of spastic muscles produces a relative inhibition of the potential activity of their antagonists. In the leg spasticity is most pronounced in the extensors of the hip, knee and ankle, and the supinators of the foot. The toes may be in dorsiflexion while the foot is plantiflexed, but if the foot is passively dorsiflexed the toes plantiflex and give resistance to dorsiflexion(1).

In addition, when the foot is off the ground, the ground reaction no longer exerts a pronation force on the subtalar joint and it supinates(2).

Since contracture develops quickly in the presence of spasticity and it may present as tonic or clonic, there is a need for an off-the-shelf ankle splint which can be worn for extensive periods of time and is designed to accommodate the neurologic foot.

BACKGROUND

Many types of pre-fabricated ankle devices have been utilized in the past. Some were designed as resting splints for the flaccid foot which are relatively flexible.

Other, more rigid splints are designed for patients with contractures resulting from orthopedic problems. Still others have been modified splints designed for ambulation. In any of these cases, the splints are either too flexible, provide abnormal sensory input to the foot or are too cumbersome and cannot be donned and doffed in a consistent manner by various staff dealing with the patient.

Custom splints are very useful, but lack of facilities and sometimes long fabrication time (consult to finished splint) make them less desirable in the acute phase of injury.

Casting has also been attempted but it is labor intensive, requires extra staff and interferes with monitoring devices such as arterial lines in the dorsum of the foot.

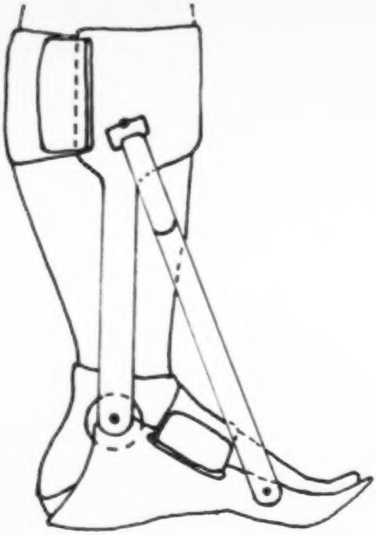
DESIGN CRITERIA

1) Total contact on the plantar surface of the foot so as not to increase positive support reactions illicted by isolated pressure on the ball of the foot.
2) Toes extended and fully supported to reduce clawing and grasping over the end of the splint.
3) Footplate pre-molded but modifiable with a heatgun if neccessary.
4) Mechanically able to control plantarflexion and supination of the subtalar joint and forefoot.
5) Access to the dorsum of the foot and open toes to visualize for capillary refill.
6) Easily and consistently donned and doffed by various staff involved with the patient's care.
7) Accommodates ranges of motion from 30 degrees plantarflexion to 10 degrees of dorsiflexion, which is needed for normal locomotion.
8) Light weight to reduce undue pressure on the opposite leg.
9) Relatively inexpensive.
10) Can be made in several sizes to accommodate pediatrics, adolescents and adults.

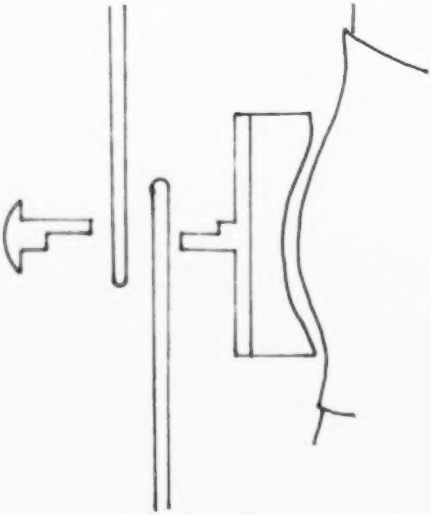
Illustrations of the proposed design are given in figures 1 and 2.

DESIGN SPECIFICATIONS

The molded footplate will be made of a high temperature plastic which would accommodate approximately two foot sizes. The heel is left open to reduce pressure on the posterior heel while the patient is supine. It could be vacuum-formed or cut and draped to shape. It will be rigid enough to maintain its shape, but may be spot heated for minimal custom molding.



ANKLE SPLINT IN
NEUTRAL POSITION
FIG. 1



ANKLE JOINT
FIG. 2

The uprights and anterior shin plate are stamped out of sheet plastic as one piece. The shin portion is then padded with self-adhesive foam.

The posterior piece is an adjustable strap to accommodate the more variable calf sizes. Since the anterior dimension is fixed, the uprights are kept in a more consistent vertical position to maintain the splints mechanical advantage.

The ankle joint is free moving with each axis centered over the maleoli approximating the anatomical axis. They are held together with ratching rivets. The inner portion is interchangeable with varying sized maleolar pads to assist in controlling pronation and supination of the hindfoot.

The heel is then wrapped in a soft strap, keeping the foot pushed forward in the splint. It then covers the maleoli crossing anteriorly and looped through slots in the upper edge of the footplate. These could be trimmed, if needed, for greater access to the pedal arteries without compromising stability.

Finally, webbing is rivetted to the footplates and drawn up through "D" rings that are rivetted to the upper portion of the uprights. These are the main mechanical levers for controlling plantarflexion/dorsiflexion of the subtalar joint and pronation/supination of the forefoot.

Although the ankle joint is free to move through a wide range of motion, it is only reccommended to 30 degrees of plantarflexion in order to assure full mechanical advantage.

DISCUSSION

A splint designed specifically for the neurologic patient could greatly enhance the efficiency of controlling the abnormal posturing of the ankle in this population. If the ankle is controlled immediately during the acute phase by a temporary means, then more custom molding or casting can be performed with greater success once the patient is medically stable.

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THE CUSTOM CUIRASS VENTILATOR - AN ALTERNATIVE FOR THE RESPIRATOR DEPENDENT CLIENT

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ABSTRACT

The cuirass is an intermittant pressure mechanical device for breathing assistance. It may be used to treat chronic respiratory failure due to neurologic deficit of the respiratory muscles or for restrictive insufficiency of lung vital capacity. The cuirass is commercially available as a stock item but for clients who have scoliosis and chest wall deformity a stock cuirass is not appropriate. The orthotist is able to use current technology of methods and materials to fabricate the custom cuirass. The cuirass offers a useful alternative to the iron lung, intermittant positive pressure and tracheostomy. The cuirass also provides the benefits of environmental contact, access for nursing care and decreased restriction of speech or mobility.

BACKGROUND AND INTRODUCTION

A cuirass is a molded plastic shell that when attached to a respirator pump provides intermittant positive and negative pressure to the external chest wall. The cuirass is fashioned after the concept of the iron lung without encapsulating most of the body. The cuirass actually outdates the iron lung having been first developed in 1874 by an Austrian - Ignez Von Hauke. This early version of the cuirass was fabricated of cane and impermeable membrane. Most subsequent externally applied devices enclosed the entire body.

The cuirass has become favorable because of obvious disadvantages of the iron lung such as high noise level, restriction of movement, deprivation of physical contact with other people and inaccessability for nursing care.

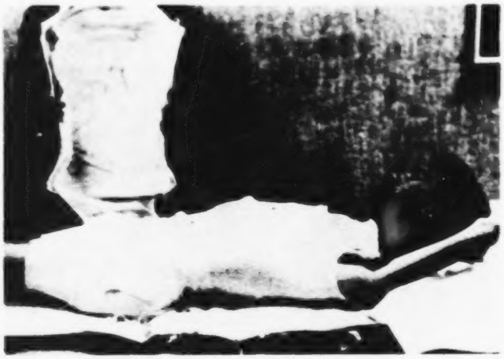
The cuirass works on the principles of replacing or assisting respiratory muscles that have lost innervation or tone. Children and adults with polio or post polio sequlae, muscular dystrophy and spinal cord injury are all potential cuirass users.

The ultimate function of the cuirass respirator is to even out blood gas in the circulatory system. Most problems stem from the inability to exhale carbon dioxide when a client sleeps. Too much carbon dioxide in the blood produces symptoms such as morning head aches, palpitations and increased daytime fatigue or insomnia. Insomnia is probably due to fear of dying during sleep.

METHODS

Stock cuirasses are available in sizes to fit youth to adults. The standard prefabricated cuirass cannot be used in the presence of scoliosis or chest wall deformity. A custom cuirass can be fabricated in any lab where plaster of paris casting, modeling and plastic forming are done routinely.

A plaster splint negative mold of the trunk is done of the same manner as for a spinal orthosis. It is best to delineate trimlines on the negative cast. The anterior superior trim in 1" below the supra-sternal notch following a line laterally 3/4" below the clavicle and along the delto-pectoral groove. The most lateral margin is just past the midline of the body. The inferior edge is 1" inferior to the ASIS and just above the symphysis pubis. The plaster impression should extend at least two inches outside the actual trimlines. It is helpful to determine in what position the client prefers to sleep.

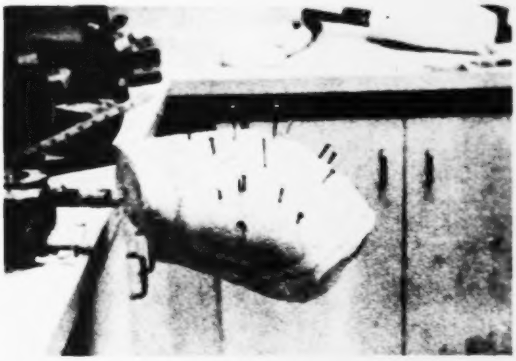


The positive model is modified with a reinforced plaster buildup to allow a finished clearance of 3" to 4" above the chest. The shape is determined by the individual patient's needs such as accomodation of sleeping position large abdomen or short neck. The clients body should not contact the inner self on inspiration. There should be a flattened area where the hose connector is attached.

A variety of thermoplastic materials are used for custom cuirasses including polyethalene, polypropylene and suralyn. The Rehabilitation Engineering Center of Children's Hospital at Stanford uses suralyn primarily because the transparency of that material allows ease in checking fit and viewing expansion of the clients chest.

The material is trimmed from the model and pre-fitting of the shell is recommended before the seal is applied. The edge should contact the body precisely. A 1½" sealing edge is maintained. Final steps in finishing include attachment of straps and the seal edge. The seal or "gasket" can be fabricated of celoflex insulation, spenco, plastazote or T-foam.

Functional testing should be done in coordination with a respiratory therapist who can monitor blood gases and lung capacity. A respirator pump such as the Monahan or Thompson should be purchased or rented by the client.



DISCUSSION

The custom cuirass ventilation system provides another alternative to a variety of systems and methods available. It is simple and less invasive than other methods. Adjusting to the use of a cuirass can still be difficult for the client and the family. The client must build up tolerance to increased chest movement and contact points of the cuirass seal.

Over one dozen custom cuirasses have been fitted at Rehabilitation Engineering Center of Children's Hospital at Stanford. We feel the materials used could be improved. Suralyn fatigues after about two years and must be replaced. A harder shatter proof plastic would be preferred. We are looking for a more durable and skin tolerant material for the edge seal. Future efforts should include research to improve the materials and gather more conclusive evidence about the value of the system.

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AN ULTRASONIC BLADDER SENSOR FOR PERSONS WITH INCONTINENCE

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ABSTRACT

The National Headquarters of the Association for Retarded Citizens is developing and testing a portable, non-invasive ultrasonic bladder sensor designed to facilitate independence in toileting. Assisting the ARC are scientists at the NASA Langley Research Center, the NASA Technology Applications Team, and medical personnel from the University of Tennessee and the Medical College of Virginia. This device could have application to the needs of many of this country's 12 million persons who experience urinary neurological dysfunction or learning impairments. The composition of this group includes persons with advanced age, multiple sclerosis, spina bifida, quadriplegia, diabetes, and mental retardation.

INTRODUCTION

Technology has been utilized in bladder control programs in the past, but the applications have been limited to devices that alert the user after urination has already begun (e.g., a moisture-sensitive device in the clothing or bed and motion-sensitive devices in the toilet). Although the knowledge that urination has commenced is useful for social and sanitary reasons, this approach does not help the user recognize the preliminary need to urinate. It is precisely the individual's association of this feeling of fullness with the standard bathroom routine that leads to independence in toileting. To this end, the ARC's ultrasonic bladder sensor provides the user with subtle external signals that coincide with the critical internal sensation. The device continuously monitors the volume of urine in the bladder and then emits one of several available signals to the user when a predetermined level of bladder fullness is reached.

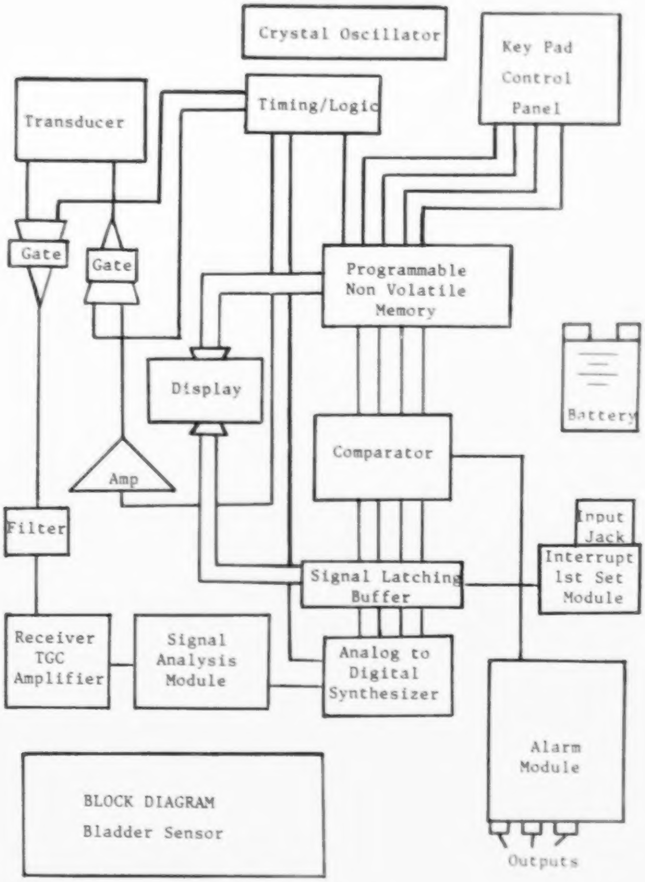
BACKGROUND

Ultrasonography is a technique used to detect body organs. Bursts of energy, generated by exciting a piezoelectric crystal, are transmitted through the skin and into the internal anatomy. When the crystals are excited, they "ring" at their characteristic resonant frequency, and the oscillations decay exponentially according to the specific design used. As the ultrasonic energy travels through the body, reflections are sent back toward the crystal when a pulse strikes a tissue interface. When this echo reaches the crystal it causes it to "ring" again, although to a lesser extent than that resulting from the original excitation that began the process. A transducer converts this "echo" into an electrical signal, the signal is amplified, and the instrumentation analyzes the signal and translates it into information about the internal structures. Ultrasonic imaging of the bladder is a common diagnostic procedure, but the current state-of-the-art requires that patients remain supine and immobile. These limitations preclude the use of ultrasound technology away from the clinical setting. In order that users might benefit in their daily lives from the information available from ultrasonic scanning of the bladder, a system would need to be designed that was small, unobtrusive, lightweight, and portable. Further, such a device would need to be sufficiently durable to withstand abusive handling, dirt, and moisture. The ARC bladder sensor incorporates all of these features in addition to programmability, which allows it to be individualized to accommodate the anatomical and behavioral differences found in the various user populations.

PROJECT DESCRIPTION

Several priorities are being addressed within the three years of the project. Among these was the consolidation of a database on urinary incontinence that includes information from incontinence product manufacturers and research reports pertaining to urinary incontinence and related topics. The Medical College of Virginia was instrumental in determining the guidelines for anatomical placement of the bladder sensor's transducer following a study conducted to examine the various stages of bladder distention across subjects.

ARC and NASA researchers designed and constructed a prototype system consisting of a logic analyzer and a single miniature transducer. The primary objective during this phase was the development of a system that would return data comparable to that obtained from currently-available clinical ultrasound equipment. Secondary objectives were to obtain the most informative scan of the bladder for as little energy expenditure as possible and to keep the cost of the device low. Development was characterized by a sectionalization of the device into discrete functional blocks so that each was independent of the others. This modularity permits relatively simple adaptation of any component rather than a reworking of the entire system should modifications be desired (see Figure 1). Toward the goal of low cost, we attempted to incorporate as many off-the-shelf components as possible. In terms of energy consumption, a technique was devised that allows the system to use much less power than had previously been required without sacrificing effectiveness. This new approach may also permit the system to rely on a single transducer rather than the two that were originally anticipated.


Crystal Oscillator
Key Pad
Control
Panel
Transducer
Timing/Logic
Gate
Gate
Programmable
Non Volatile
Memory
Display
Battery
Comparator
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Jack
Filter
Signal Latching
Buffer
Interrupt
1st Set
Module
Receiver
TGC
Amplifier
Signal
Analysis
Module
Analog to
Digital
Synthesizer
Alarm
Module
BLOCK DIAGRAM
Bladder Sensor
Outputs

Figure 1

Miniaturization of the logic analyzer to the approximate size of a credit card calculator and placement of the transducer in a supportive apparatus (see Figure 2) will facilitate more comprehensive testing of the device with representatives of potential user populations in both educational and vocational settings. Evaluation will address the functioning of the hardware and software, the nature and degree of behavior change evidenced by the subjects, and the interrelationship among the device, the user, and those with whom the user interacts.

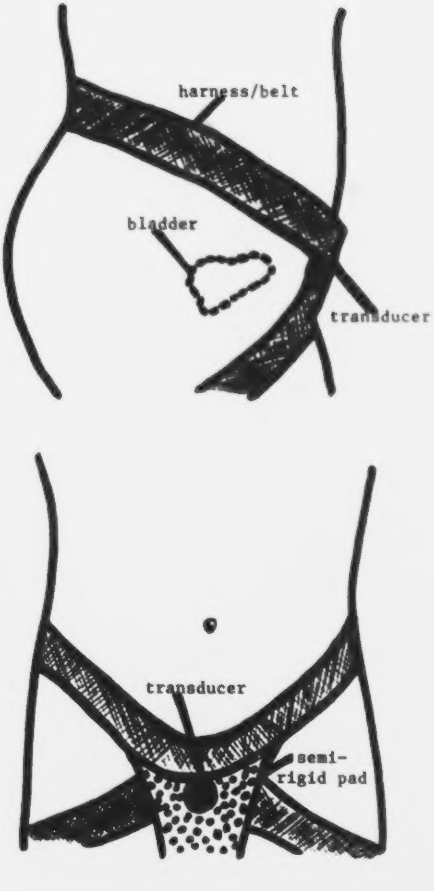

Figure 2

APPLICATIONS

While the original purpose of this project was to develop a device for use by persons with mental retardation and other disabilities, it appears that the device may have application to other populations as well. Indeed, any person in need of an enhanced signal that urination is imminent might benefit from the use of this device. This group would include the millions of bedwetters and, far more common, the entire population of one- and two-year olds enduring their parents' best attempts at toilet training.

It is the intention of the ARC that the use of this device by persons with mental retardation, excluding those with confounding organic problems, be temporary. In these cases the device would be a crucial component of a training program designed to facilitate the awareness of the internal sensation of a full bladder and the learning of the association between this feeling and the commencement of the toileting routine. Once these objectives are achieved, the use of the device as a prompt is no longer necessary. For those with medically-based incontinence, the device would remain in use as long as the need for it continued to exist.

ACKNOWLEDGEMENTS

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Micro-Enema Dispenser for Quadriplegics

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ABSTRACT

The implementation of a bowel care program which can be carried out in an independent manner is an important goal for many quadriplegics. The development of a micro-enema has decreased the time required for a bowel movement but unfortunately, it requires an aide to administer it.

This project describes the development of a prototype model of a micro-enema dispenser which would allow level C6 and C7 quadriplegics to administer the enema independently. The design, operation and laboratory testing of the prototype is presented as well as discussion pertaining to the successful attainment of all design constraints.

INTRODUCTION

A quadriplegic's bowel system normally does not function properly on its own. It must be regulated through the use of special diets along with suppositories or enemas (1). A suppository requires between one and two hours to stimulate a bowel movement. Since it is used every other day, it can be a source of considerable inconvenience for the user. However, a quadriplegic can administer it using a suppository gun which provides a certain degree of independence in the bowel care program.

The development of a micro-enema, which requires only 5 - 30 minutes to effect a bowel movement, has provided a potential means of reducing the time factor associated with the use of suppositories. At present, the micro-enema must be administered by an aide. Since no device is currently available which would accommodate its independent use by the quadriplegic, the design of such a device would allow independent quadriplegics to utilize the positive benefits of the micro-enema.

This paper presents the development and design of a micro-enema dispenser to be used specifically by level C6 and C7 quadriplegics. A brief outline of some of the preliminary laboratory results illustrating its performance is included. Discussion pertaining to the full testing of the dispenser and its marketability shall also be presented.

DESIGN CONSTRAINTS

In developing the dispenser, certain constraints were identified and are summarized as follows (2). The device must be:

1) lightweight,
2) hygienic (ie. washable),
3) durable,
4) safe,
5) inexpensive,
6) designed to the physical constraints of C6 and C7 quadriplegics,
7) easily cleaned and its parts readily replaced

In addition, the design of the dispenser must operate such that the micro-enema tube tip is fully inserted before fluid expulsion. Once inserted, the device must expel 5 ml of fluid from the tube.

DESIGN PHILOSOPHY & CONFIGURATION

After an in-depth consideration of the design constraints, it was ascertained that the basic operation of the micro-enema dispenser had to emulate the squeezing action performed by an aide who would normally administer the enema. The physical limitations of level C6 and C7 quadriplegics restrict their actions in the use of a device to that of placement of the tube into the dispenser, and insertion of the tip into the anus. The action of squeezing the fluid from the tube must be accomplished using some external power source.

Many configurations were considered; the final form is displayed in Figure 1. The dispenser consists of two contoured, hinged arms. (A) Application of a uniform force along the outside of the arms provides the necessary squeezing force on the micro-enema tube, which is inserted between the arms as illustrated. The uniform force is achieved by pressurizing two balloon-type containers along the hinged arms. (B)

Since preliminary studies indicated that a pressure level of 3.4 to 10.3 kPa (0.5 to 1.5 psig) would be sufficient to dispense the fluid from the tube, it was decided that the pressure source could be air expelled from the user's lungs. Consequently, a mouthpiece and hose attachment was added to the assembly, providing a path for the air from the user to the balloon.

To incorporate the mouthpiece and hose attachment, a y-union was used to connect the single line from the mouthpiece to two seperate lengths of tubing. (C) These tubes, in turn, were fitted to the dispenser base by pipe-to-hose connectors sealed in the base with O-rings. (D)

To provide the necessary interfacing between the pipe-to-hose connectors and the balloons, two removable wedges were designed to fit snugly over the end of the connectors. (E) The balloons were attached with O-rings to acrylic tubes which extend from the wedges to the pipe-to-hose attachment. The wedges are held secure by a pin through the dispenser wall. This arrangement permits a convenient means of disassembly and assembly for cleaning purposes.

The wedges, balloons, and arms are contained within a rectangular holding device, which in turn fits into a cylindrical shell. (F)

A circular lid, held with velcro fasteners, holds the tube in the dispenser. (G) The tip of the tube extends beyond the assembly through a small hole in the lid. The body of the tube is located inside the assembly between the contoured arms. A cloth barrier prevents the tube from being placed too far into the dispenser. The assembled system is illustrated in Figure 2.

OPERATION

The procedure required to use the micro-enema dispenser has been developed with simplicity in mind. After placement of the micro-enema tube in the dispenser, the user slips his hand into the handle and inserts the tube tip in the rectum. Using a proper blowing procedure with the mouthpiece held between the teeth, the micro-enema fluid is then dispensed. This procedure would require a training program and much practice. Most quadriplegics would perform the micro-enema while lying on a bed. Depending on individual ability or preference, the quadriplegic may use a disposable pad to catch the excreted stool or transfer quickly to a commode to complete the bowel movement.

MATERIALS SELECTION

The dispenser body, arms, wedges, and contours are made from acrylic because it is lightweight, hygienic, durable, and inexpensive. As well, acrylic is transparent; thus, the user can see the internal workings of the device. In this study, condoms were used as the balloons because they expand uniformly and retain their original shape when deflated. Brass fittings and corrosion-resistant hinges were chosen. Nylon tubing is used because it is flexible, hygienic, and durable. The handle is made of aluminum covered with a shrink-fit plastic coating.

TESTING

With the help of several level C6 quadriplegics, testing was conducted to determine the lung pressures that could be developed by the users. The quadriplegics were asked to blow into a length of hose attached to a pressure gage for as long a period as they felt comfortable. The average pressure sustained was 6.9 KPa (1.0 psig) for 18 seconds. This confirmed the original assumption that the user could provide an adequate pressure level to squeeze the fluid out.

Testing of the prototype was then conducted in the laboratory. Using air pressure levels set by the aforementioned lung pressure tests, air was mouth-blown into the dispenser. This air inflated the balloons and caused the contoured arms to close on the micro-enema tube. The fluid was expelled into a graduated cylinder. A variety of blowing methods was attempted to achieve the required expulsion.

The most suitable method was a series of short pressure spurts of 5.5 KPa (0.8 psig) held for 1 second followed by long pressure spurts of 8.3 KPa (1.2 psig) for 5 seconds. The total time necessary to completely dispense the micro-enema fluid was approximately 30 seconds. This pressure supply method may vary for each individual and would be determined by initial training of the quadriplegic. The blowing procedure is started after the micro-enema is inserted in the rectum.

DISCUSSION

The micro-enema dispenser satisfies the pre-set design constraints in the following ways.

1) The prototype is made almost entirely of plexiglass, which is lightweight, inexpensive, and hygienic. The design is very durable and requires little maintenance other than occasional replacement of the balloons.

2) The dispenser may be easily cleaned by flushing with water. For a more thorough cleansing, all the parts may be removed and washed individually. Note that this cleansing may or may not be performed by the quadriplegic on his own, depending on individual ability.

3) The dispenser is compact and portable. Thus, it may be used away from home.

4) Since the fluid is only expelled when the user wishes, the tube can readily be totally inserted before this action is initiated through blowing.

5) Laboratory tests indicate that 5 ml of fluid could be expelled using the device.

6) The total cost of one prototype (materials plus labour) is approximately $100. This compares to the retail cost of a suppository gun and hence meets the cost constraints placed on the design. It must be noted that the cost quoted here is based on one prototype. It is impossible to predict the cost of a dispenser if many were produced, since the method of manufacturing and the number produced would affect the price.

CONCLUSIONS

It is believed that the micro-enema dispenser is a viable, inexpensive method of dispensing the micro-enema fluid which may be used by independent level C6 and C7 quadriplegics. The device has met with initial acceptance (concept and configuration wise) from quadriplegics who participated in the breathing capacity tests. Applications for training of interested quadriplegics in the use of the device has now been sought through the University Ethics Committee. Once testing procedures have been approved, dispenser models will be fabricated and an extensive research program initiated through the Occupational Therapy and

Rehabilitation Medical Department at the University Hospital will be carried out.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the participation of the patients and staff of the Occupational Therapy and Rehabilitation Medicine Departments at the University Hospital in Saskatoon as well as members of the Mechanical Engineering Department at the University of Saskatchewan.

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Figure 2
MICRO-ENEMA DISPENSER PROTOTYPE

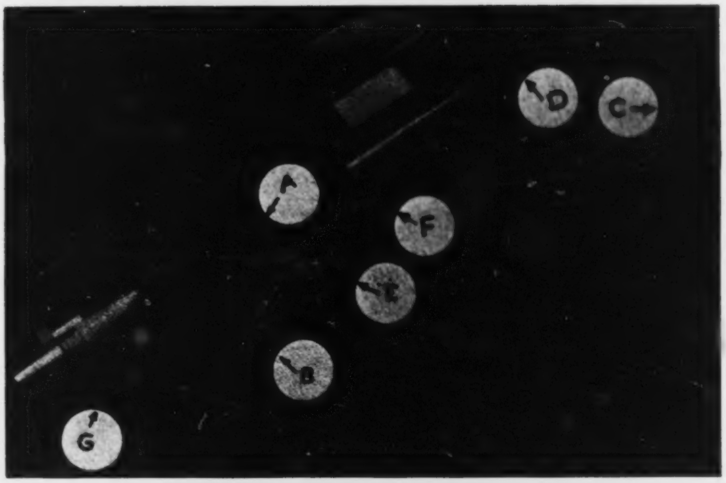

Figure 1
COMPONENTS OF DISPENSER

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Special Interest Group 5

Quantitative Assessment

Chair: Robert P. Patterson, Ph.D.

QUANTITATIVE TESTING TECHNOLOGY:
OVERVIEW / MARKETING ISSUES

Robert Patterson, Session Chairman
University of Minnesota, Minneapolis

The measurement of human performance and functional capability has been studied and used for a long time in research laboratories but has not seen wide spread use in rehabilitation. The development of simple, valid, reliable and easy to use tools is difficult, but equally difficult is getting medical and rehabilitation community to accept and use the tools available. Many people may not be familiar with the measurement tools or know about their availability. But also many people, particularly in rehabilitation, have a direct "laying on of the hands" approach both for patient assessment and treatment. This probably results from the many humanistic issues associated with rehabilitation and the type of people who enter the field and the type of training they receive. This must change somewhat in order to effectively apply new technologies and to evaluate the efficacy of new treatment modalities.

The purpose of the two parts of this session is to address issues that will lead to a wider use of quantitative assessment tools. The first part will consist of presentations by experienced researchers in the field on tools, techniques and methods that are available or are close to being available that can be used by the rehabilitation community. The nature of the presentations will be tutorial.

The second part will be a round table discussion focusing on economic factors. The increasing requirements for the documentation of rehabilitation services for third party payers appears to have a strong influence on the need for quantification. To date, it appears much of the documentation is not based on objective measurement. The discussion will focus on the actual need and desires of the rehabilitation community to purchase and use quantification tools. Manufacturers want to be assured that if they develop quantitative assessment tools there will be a market that will purchase their equipment. We hope to shed light on this problem.

These issues will have a significant influence on clinical rehabilitation and on the utilization of rehabilitation engineering services. This session should offer much for both the beginner and expert alike.

THE AVAILABLE MOTIONS INVENTORY: EVALUATION TOOL FOR THE PRODUCTIVE EMPLOYMENT OF HANDICAPPED INDIVIDUALS

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Janis G. Krohe, M.B.A.
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ABSTRACT

An evaluation system, the Available Motions Inventory, AMI, was developed at Wichita State University in cooperation with the Cerebral Palsy Research Foundation of Kansas, Inc. The utility of the evaluation is to assess the work aptitudes of persons with physical disabilities. The evaluation was initially utilized to assess the individual's ability to interface with manufacturing machine tools. More recent refinements provide for its application to any functional environment, such as white collar occupations, independent living, educational and recreational activities. The evaluation has been administered to more than four hundred disabled individuals. The results have been used to place such persons in a variety of occupational and independent living environments.

INTRODUCTION

The Available Motions Inventory, AMI, is the most comprehensive assessment system currently available for documenting residual capacities possessed by physically disabled individuals to perform occupational tasks. It has been utilized by the Cerebral Palsy Research Foundation since 1972 in its effort to place such persons in competitive employment. The AMI apparatus has been placed in twelve other rehabilitation agencies in the United States and one each in Canada and Egypt.

BACKGROUND

A basic philosophical stance of the Cerebral Palsy Research Foundation of Kansas is that when the medical phase of the rehabilitation process is complete and the individual's functioning has been altered and/or modified by surgery, therapy, orthotics and prosthetics to every extent possible, it is then appropriate to investigate the potential for modification of the environment in which a disabled person proposes to function.

The impetus for the development of the AMI was the need to measure objectively the ability of some physically limited individuals who were candidates for employment in industry in Wichita, Kansas. Traditional work sample assessment systems did not appear to yield pertinent information because these individuals tended to perform activities in a very atypical manner.

An integral part of the placement plan for the disabled individuals was the modification of proposed worksites by staff engineers such that the disabled individuals could perform their assigned tasks well enough to merit minimum wage and, therefore, be competitive with their able-bodied work peers. The AMI provided the analysis of the individual's functioning and the design criteria for engineering modifications.

METHOD

Initial design procedure

Worksites in the Wichita area were surveyed in order to identify a repertoire of tasks required to perform work in an industrial setting. The hardware required to perform such tasks was attached to 12" square modules which could be mounted on a test frame at a variety of orientations relative to the body position of the person to be evaluated. This hardware consisted of a variety of switches, control handles to sample settings and rate, and handles to test strength. A separate station was used to evaluate ability to assemble small hardware items. Later, a station was added to sample response time an auditory or visual stimulus and speed at reaching a required distance.

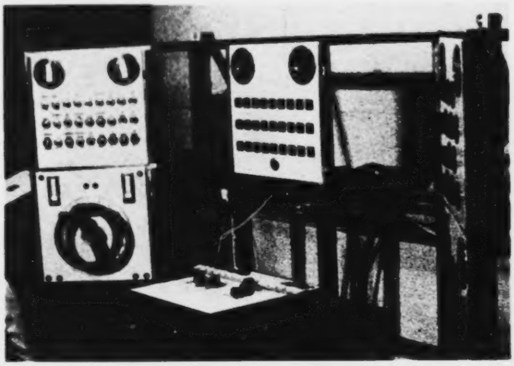

Figure 1 The Available Motions Inventory Apparatus

A survey of potential clients whose limitations were most appropriate to the characteristics of the AMI evaluation revealed two generalizations; first, the majority of potential evaluation subjects were able to perform evaluation tasks only from a seated position; second, most subjects possessed different functional characteristics between hands. Therefore, the evaluation was designed to be performed by a subject in a seated position; further, evaluation items were to be performed by each hand independently.

Pilot evaluations
The sequence of evaluation tasks was administered to a a small group of able-bodied individuals in order to establish tentative norms. The evaluation was administered to a pilot population of disabled individuals and then to candidates for placement in mainstream industry in the Wichita area.

Practical utilization
Center Industries Corporation, CIC, was founded in 1975 as an experiment in integrated work settings for disabled persons. Its work force is divided on a ratio of 75% disabled persons to 25% able-bodied persons. Initially, all disabled persons proposed for placement at CIC were evaluated using the AMI. Deficits perceived in the individual's functioning were augmented by the use of adaptations to the manufacturing equipment.

Evaluation refinements
The items which were identified and incorporated into the AMI have remained relatively stable since 1973. The refinements of the AMI system have been for the purpose of improved data analysis. Following the pilot evaluation, the normative population was increased to fifty persons; recently norms based on the performance of one hundred able-bodied persons have been established. The data analysis system initially focused on the scores achieved on individual tasks. A revised analysis system yields scores which indicate at which orientation relative to the body and which general class of activity an individual best performs. A final analysis allows the AMI results to be transferred to any type of activity. All 71 AMI tasks were evaluated to determine the requirements to perform each. These requirements were classified into the body member (fingers, hand, and arm) primarily involved and the type of motion (one, two, three-dimensional, and rotary) required to perform the task. A similar motion class analysis of the proposed activity facilitates the transfer of AMI information to the desired setting.

RESULTS

The Available Motions Inventory is an effective tool to assess objectively an individual's potential to perform given operational tasks. Generalizing of the information allows for more flexible application of the information gleaned from administration of the evaluation. It has also proven to be an effective diagnostic measure. Application of the data derived from the AMI has been expanded to assist rehabilitation engineers in designing appropriate adaptations to work sites in white collar settings, within the home, and for children in educational settings. The following case study is presented as an illustration of the utility of the AMI to develop customized worksite modifications.

Case study
The AMI was administered to an individual whose ability to perform hand operations was severely limited. Hemiplegia rendered only one hand useful and eye/hand coordination was very poor. Analysis of the data indicated that the one useful hand could perform fairly effectively in a spatial twelve-inch cube, located at shoulder height and to the right of midline. The worksite was modified so that part procurement, machine loading and activation, and delivery of the finished part all occurred within the space of optimum performance. The worker could not select one unprocessed part from a bin full of parts so an individual parts feeder was fabricated which presented the parts one at a time. The idea for the parts feeder was conceived from a device designed to present an individual toothpick to a restaurant diner without allowing access to other toothpicks in the holder. The hand motions required to perform the entire operation were simplistic, one or two-dimensional motions. This custom adapted worksite enabled an individual, previously considered too severely impaired, to perform work to achieve an economical piece rate.

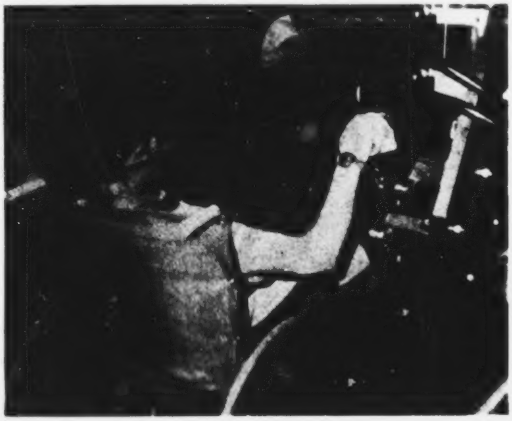

Figure 2 Worksite Modification Design from AMI Analysis

Generic modifications

Analysis of AMI evaluation data reveals some general patterns of disability. The disability classification with the highest incidence among those within the age range for potential habilitation or rehabilitation is cerebral palsy. Some pervasive characteristics of subjects affected by cerebral palsy are poor fine motor coordination and hemiplegia. These limitations can be accommodated be worksite modifications. Poor fine motor control can be alleviated by structures (jigs, fixtures, fences, etc.) which control the alignment of materials or parts to be processed and limit the motion to a prescribed direction. To accommodate hemiplegia, a task is redesigned so that so that it can be accomplished using only one hand. Persons disabled by other conditions can be served on an individual basis depending on their unique characteristics.

Robotics

Another arena of adapted worksite appears to be the utilization of robotics. An experimental effort of the Cerebral Palsy Research Foundation of Kansas employs a relatively inexpensive robot to perform the discreet movements of a work task. The AMI analysis revealed that a severely disabled worker could most effectively perform gross motions, while fine motor coordination was poor. By utilizing the robot to perform fine motor tasks, the severely disabled worker could use gross motions to place the parts for processing in a holding fixture to be picked up by the robot. The worker monitors the robot's activity, stopping it if the operation goes awry. The worker can reinitiate the activity after adjusting the position of job components. Usually this can be accomplished without assistance.

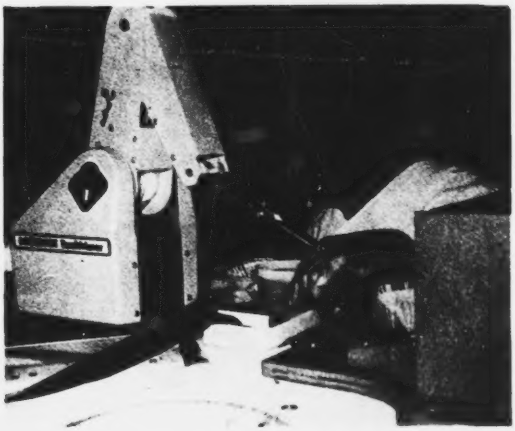

Figure 3 Robotic Activity
Controlled by Disabled Worker

CONCLUSIONS

The Available Motions Inventory appears to be a valuable assessment tool to determine the residual capacities for disabled persons to perform operations in a variety of settings. Its extensive utilization in the industrial workplace does not preclude its applicability in white collar, independent living, and educational settings. Its pragmatic approach to analysis of the motions required to perform an activity and comparison to motions present in a disabled person's operational repertoire makes it useful and flexible in its application.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the role of the President and Founder of the Cerebral Palsy Research Foundation of Kansas, Inc., John F. Jonas, Jr., in his envisioning the utility of engineering to assist the severely disabled person to be productive in occupation. The cooperation of the faculty and staff of the College of Engineering, The Wichita State University, in the development of the design, fabrication, and data analysis system of the AMI is appreciated.

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QUANTIFICATION OF MUSCLE STRENGTH, MUSCLE ENDURANCE AND RANGE OF MOTION

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ABSTRACT

A computerized isometric muscle strength endurance and response time measurement and exercise system (SIMS) has been developed and tested. It can measure all major muscle groups in the body including the neck, back, shoulder, elbow, hip, knee and ankle.

INTRODUCTION

In order to provide optimum rehabilitation services to individuals with physical disabilities, it is important to measure muscle strength, endurance and joint range of motion. The tracking of changes in muscle strength is important in degenerative diseases(1) in order to assess the subtle effects of various drug treatments or to predict changes in medication regimens. Comparing the strength or range of motion between each side of the body can be used to plot recovery or lack of recovery from injury. The efficacy of various physical modalities can be determined. This is important in research on new and existing modalities and more recently it is becoming increasingly important in order to obtain payment from third parties.

BACKGROUND

The manual muscle test has been the clinical standard to document muscle strength. Table 1 shows the rating scale which ranges from 0 to 5.

TABLE 1

MANUAL MUSCLE TESTING RATINGS

Number	Description	
5	Normal	Complete ROM against gravity with full resistance.
4	Good	Complete ROM against gravity with some resistance.
3	Fair	Complete ROM against gravity.
2	Poor	Complete ROM with gravity eliminated.
1	Trace	Evidence of slight contractility. No joint motion.
0	Zero	No evidence of contractility.

The manual muscle test is quick and easy to apply but does not produce consistent inter or intra tester ratings. This is particularly true in the upper ranges of the scale with ratings of 4 or 5.

Starting in 1945, Beasley(2,3) conducted a very extensive comparison of manual muscle testing with quantitative testing. In a series of studies involving thousands of subjects he compared the strength of the flexors and extensors of the knee, hip and ankle measured with a force transducer against the manual muscle test ratings made by experienced testers. In one series a group of 752 post polio patients rated as having normal knee extension strength of one half that of subjects with a negative history of injury.

In order to develop a quantitative muscle strength testing system it is necessary to provide not only a force transducer to quantitate the force measurement but it is also very important that necessary stabilization be provided in order that only the torque around the joint to be measured can contribute to the force measurement. For example, if the elbow flexion torque is to be measured at the wrist, it is important to stabilize the shoulder to prevent shoulder elevation from contributing to the force measured at the wrist. Providing stabilization that is quick and easy to apply for testing all the major muscle groups is one of the most difficult problems encountered in developing a quantitative muscle strength testing system. The goniometer is the standard measurement tool of the physical therapist and the physiatrist for measurement of joint range of motion. The device works well for the extremities but is unsatisfactory for the cervical spine (the neck) and the back because there are no easy to use reference points. Various systems using either gravity sensitive goniometers or photographs have been used in the past.

METHODS AND RESULTS

Forced measurement - system for isometric muscle strength (SIMS) testing

The SIMS consists of a chair/table combination (Figure 1) that can quickly and easily stabilize the body and allow positioning of the forced transducer over the region to be measured. The system can measure 23 different muscle groups including the neck, back, shoulder, elbow, hip, knee and ankle. The SIMS also has a computer processing system that signals the subject to contract his/her muscle and then calculates and records peak force, mean force, delay times and rise times of the force as shown in Figure 2.

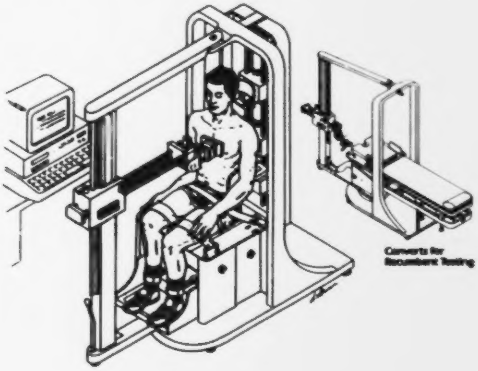

Figure 1: The SIMS System

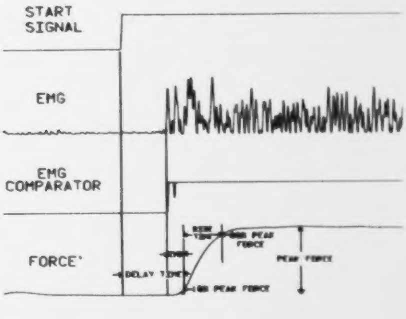

Figure 2: Force and time parameters measured

The instrumentation can measure the EMG to provide timing information to determine the elctromechanical delay associated with the muscle contraction. Software also exists in the system to perform frequency analysis on the EMG to track changes in the mean frequency of the EMG in order to measure fatigue.

The system can be selected to do either muscle strength testing, muscle endurance testing or exercise. The strength testing program can make from one to five rapid measurements of maximal muscle strength with a duration up to 10 seconds and a programmed timed rest period between each trial. The muscle endurance testing is programmed to allow the subject to work with selected work-rest cycles at any percentage of his/her maximal strength for repeated periods up to five minutes. The program can be selected to stop when the force falls to a percentage of the selected work level or for a fixed work time. The exercise option allows the user to have the subject exercise at ten different combinations of work levels and rest time periods. The computer can be programmed to direct the subject to make repeated contractions at a given level, then rest for a period of time, followed by contractions at another level, followed by another rest period, and again followed by a contraction at a higher level, for up to a total of 30 minutes. The user can select the exercise protocol choosing options from a table. The only calculations executed by this program are the average force, the work time and the number of effective contractions with force > .8 of the selective work level.

RANGE OF MOTION

The simple goniometer cannot be used for range of motion measurements of the neck and back. In our laboratory we have developed a simple mechanical goniometer for the neck which is shown in Figure 3.

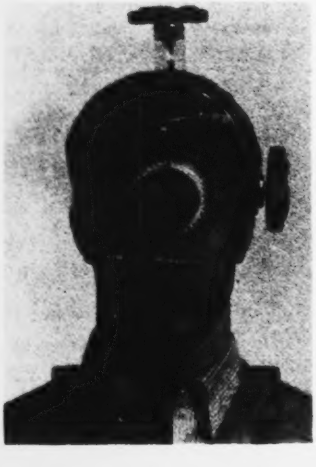

Figure 3: Subject with mechanical goniometer

It uses bubble goniometers attached to a glasses frame, which can be easily applied to the subject for flexion and extension measurements and lateral bending. For rotation, a cable is attached to the frame from the top of the head to a fixture attached to a shoulder saddle.

An alternate, fully-automatic, approach to measuring cervical range of motion is shown in Figure 4.

Figure 4: Cervical range of motion head piece

This approach uses a video camera attached to a video digitizing board and an Apple computer. The subject wears a head piece which LEDs are lit by the computer in a given sequence to measure flexion, extension, and lateral bending and rotation. The system is fully automated. The computer finds the position of the LEDs and calculates the angles. The patient has a button to push which indicates when in the range of motion, tightness occurs, pain first starts and final limits are reached. All this information is given on the graphical print out. A print-out of the range of motion scale is shown in Figure 5.

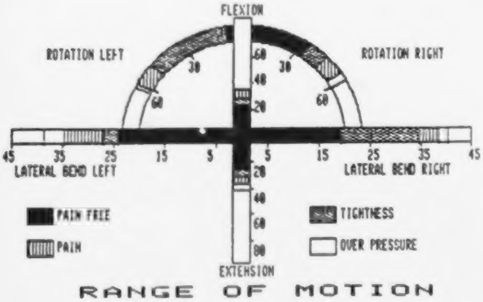

Figure 5: Range of motion print out

The total cost of the video camera and digitizing board is approximately $500. A system can measure the angles with an accuracy of better than 5 degrees.

DISCUSSION AND CONCLUSION

A computer-based system has been designed and tested. It can measure muscle strength, endurance and response time for all major muscle groups in the body. The system has been proven to be easy and quick to use. The system is commercially available which will allow the general rehabilitation community to increase its use of quantitative measurement technology.

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QUANTITATIVE FUNCTIONAL ASSESSMENT IN A UNIVERSITY REHABILITATION ENGINEERING CENTER

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ABSTRACT

Quantitative functional assessment is defined and described as practiced in a rehabilitation engineering center in a university-medical center complex. The rehabilitation "products" are people, processes and devices. Selected specific case studies illustrate the history from conception through availability to the end user. Individual projects in the contemporary Harvard-Massachusetts Institute of Technology Rehabilitation Engineering Center (H-MIT REC) program are described briefly, their interrelationships and integration explained, and the plans for technology transfer and marketing outlined.

INTRODUCTION

Although technology-based assistance to disabled persons has a very long history, the institutionalization of the field in the form of federally supported Rehabilitation Engineering Centers is now 15 years old. The H-MIT REC supported by the National Institute on Disability and Rehabilitation Research, focusses on Quantitative Functional Assessment (QFA). The evolution of the H-MIT REC into a QFA thrust reflects an earlier decade of experience addressing the specific impairments of blindness and limb amputation in an engineering-rich environment with strong clinical/medical/-rehabilitation connections. That earlier introduction into what we now call Rehabilitation Engineering was in turn preceded by a decade and a half of experience at MIT which demonstrated that novel concepts could be converted into practical solutions in a university setting with engineering faculty and students collaborating on the research and design of components for air-to-air and ground-to-air missiles and computer-aided design. The MIT efforts in both of these areas were guided by, and were in turn responsive to, ultimate practical utilization. The missile research provided control and power components which contributed to the success of the Sparrow and Hawk missiles, and the computer-aided design studies prepared the ground work for and foretold what has become a major industry called CAD/CAM. Lessons in technology transfer we learned in these earlier experiences have influenced the practice of rehabilitation engineering at MIT over the last quarter century.

BACKGROUND

The contemporary H-MIT REC traces its origins to research at MIT on braille translation by computer, on computer-driven braille embossing typewriters, and on portable braille recording and playback devices; on mobility aides for blind travelers and cybernetically controlled, naturally responding, artificial limbs for amputees (3). The researchers (then in the Sensory Aids Evaluation and Development Center for the blindness related work and the Engineering Projects Laboratory for the prosthetic limb studies) assumed responsibility for the dissemination of their results. The braille translation codes were widely distributed, refined and made available to software marketers. Demonstration projects were organized at schools for the blind, braille printing presses, the IRS, etc. applying the translation programs and prototype embossers developed by the program. The current wide-scale availability on personal computers of braille translating and embossing capability is a direct consequence of these earlier university-based efforts. Mobility aids for blind travelers developed at MIT during that period are still in use and in modest production. The "Boston Arm" product of the prosthetics research, an electromygraphically-controlled artificial elbow moved into commercial distribution through collaboration with a major insurance company. Subsequently, an MIT student founded the company that produces the "Utah Arm" based in part on his Ph.D. thesis at MIT. Thus research on and the development of devices dominated the period which preceded the inauguration of the national Rehabilitation Engineering Center program in 1972.

The national REC program achieves coverage over the broad spectrum of physical disabilities by focussing the program of individual RECs on either a disability category, for example blindness and low vision, or on particular area of technological mediation, for example, adapting motor vehicles for physically handicapped drivers. For such RECs devices have become the dominant "product", reflected in the fact that two of the current RECs are specifically and exclusively committed to the development of marketing strategies to get devices into practical use by disabled persons.

This wide concentration on devices by other RECs encouraged the H-MIT REC to address another aspect of human rehabilitation. Whether the consequence of congenital defect, disease or trauma, ameliorating the disability usually involves medical, rehabilitation and engineering components which merge into a composite process of intervention and retraining which may or may not involve devices. A study of the relative magnitudes of human pain and suffering and of the economic costs of the various disabilities identified neuromuscular skeletal problems as significant. Though rarely life threatening, as with cancer and cardiovascular pathologies, the number of individuals affected, the extent, and duration of restricted activity and the medical and economic costs rank neuromuscular skeletal defects at the top of any global comparison of impairments.

Across the broad spectrum of congenital and geriatric disabling conditions and those consequent to disease or trauma, is the omni-present dearth of objective methods for evaluating rehabilitaion alternatives and the problems of quantitative measurement of the pre- and post-intervention state of the subject. Physicians in the medically-relevant fields of neurology, orthopaedics, chiropractic, physiatrics, physical medicine, pediatrics and geriatrics are not by nature or training intrinsically quantitative and objective in their approaches. The opportunity to address quantitative functional assessment in these areas was compelling, particularly in a quantitatively-oriented, engineering-based university with strong ties to collaborating medical centers. Accordingly, the H-MIT REC set as its goal the pioneering effort in QFA, designing its program so as to capitalize on the engineering resources at MIT and its prior successful experiences in rehabilitation engineering, together with the medical resources of Harvard affiliated groups at the Children's Hospital Medical Center and the Massachusetts General Hospital (MGH).

CURRENT PROGRAM OF THE H-MIT REC

We are concerned primarily with the functional assessment, diagnosis and therapy of neuromuscular, skeletal and synovial joint dysfunctions.

Within this large problem area, several current projects are derivative of our earlier research on limb amputation prostheses. Despite considerable effort, including our own, myoelectrically controlled upper extremity prostheses have not been widely applied in comparison with the size of the relevant patient population. Non-technological issues, for example cost, maintenance, the conservative approach of medical and prosthetic providers, governmental and insurance considerations etc., have been restrictive. These have been explored in an MIT Political Science Department thesis now recast as a Case Study by the Office of Technology Assessment of the Congress of the United States and published as a book. Even so electrically powered and certainly mechanically operated, artificial elbows do not begin to approach the fluidity and grace of the normal joint. How the brain controls normal movement is under intense study at MIT in collaboration with faculty members of the REC. This new knowledge concatinated with our extensive prosthetic elbow experience are producing research prostheses far more effective in prosthetic dynamic tasks than the best myoelectrically controlled limbs available commercially. Two companion papers presented at this RESNA meeting (3, 4) describe aspects of this research. A quantitative means for assessing the effectiveness of different prosthetic control schemes as the amputee addresses functional tasks and ultimately a new generation of more effective prostheses are the outcomes.

The historical interest of the MIT group in prosthetic replacement for the lower extremity amputee, has now focussed on training devices to accelerate and facilitate the acceptance and use of artificial knees by the above-knee amputee, with an emphasis on the geriatric population, which constitutes by far the greatest number with the greatest difficulties. The approach is to capitalize on the micro-computer, together with novel transducers monitoring weight-bearing and hip angle, to provide both real-time feedback on proper procedure to the patient and to the physical therapist, together with longitudinal recording of the progress of the patient. The MIT STRIDER has been well received by both patients and medical personnel at the MGH. On the basis of this experience a system easier to don, control and monitor, and using an inexpensive personal computer, is under development. (5)

The neuromuscular pathology of tremor limits the manipulative ability of many humans. A better understanding of the neurological and/or mechanical basis for tremor and its objective measurement is another interest of the MIT group. (6) The rehabilitation "products" emerging from these studies involve techniques for imposing a viscous torque on the affected joint so as to separate the intended movement from the pathological oscillation. Damped wrist and angle braces have been shown to be effective and a damped joystick for wheel chair control is being patented.

The long time alliances with CHMC and MGH have identified cerebral palsied children as a special focus. For a number of years the Gait Analysis Laboratory at CHMC developed measurement means and produced studies defining the medical efficacy of common surgical practices intended to alleviate the movement problems of such children. Currently, in the H-MIT REC the focus is on posture and balance of cerebral palsied children (7). Here the goal is identifying and evaluating aggregate quantitative measures by means of which to classify the pathological state and evaluate invasive and non-invasive procedures to improve the condition of the children.

Functional neuromuscular stimulation (FNS) to reanimate the paralyzed person , especially the spinal cord injury victim, is the subject of much research everywhere. The exciting prospects are raising puiblic expectations and have tended to displace objective assessment. The H-MIT REC has demonstrated that by linking a human operator controlling a task to the stimulation of animal muscles which achieve the task, a simulation means is created for evaluating feasibility and controllability of future FNS concepts (8).

All of the above projects - upper and lower extremity amputation prostheses, tremor, cerebral palsy, functional neuromuscular stimulation - require means to require human movement data with high precision, and for some applications, in real-time. A major over-arching effort in the REC has addressed this mobility analysis need and produced the MIT TRACK system. This electro-optical camera, sophisticated but user-friendly software and dynamic graphic display system is the premiere movement analysis system world-wide. A novel body-marker approach, using arrays of light-emitting-diodes produces precision translation and orientation information from each body segment at high frequencies. The MIT facility, which focusses on research, has been replicated in a clinical setting at the MGH.

In addition to contributing quantitative motion data to each of the above referenced REC projects, TRACK is providing the kinematic data essentially to the interpretation of the unique pressure data we are acquiring from an instrumented hip prosthesis which now has served our subject effectively for two and a half years as a replacement for her femoral head. By concurrently monitoring interarticular pressure on natural acetabular cartlige, body-segment kinematics, foot-floor interactions, and electromyographic activity from the relevant muscles, we are generating a veritable avalanche of new and exciting data which is changing surgical practice and rehabilitation protocols for all major hip reconstruction procedures. Papers at this RESNA meeting present some aspects of this study (10, 11).

The TRACK system also serves as the movement measuring system for our new concept of computer-aided surgical simulation. TRACK monitoring establishes a record of the pre-intervention state of the mobility impaired person. Then Computer Tomographic or Magnetic Resonance Imaging cross-sectional slice data are employed, via computer algorithms, to calculate the mass and inertial properties of the subjects body segments so that TRACK kinematics can be converted into accurate dynamic data, thereby quantitating the forces and moments occurring across the subjects joints (12). The same CT or MRI data is also organized, via a vast computer database and processing scheme, into three-dimensional representations of the subject's bones, muscles etc. (13) These are displayed via color computer graphics to the surgeon, who can then simulate surgical procedures and ask the computer to calculate how the putative surgical alterations would affect the mobility of the subject. Thus the surgeon will enjoy the ability to experiment, evaluate and iterate details of the surgical procedure before entering the operating theatre, or perhaps deciding that the outcome does not warrant intervention.

TRAINING REHABILITATION PERSONNEL

In addition to the rehabilitation knowledge, processes and devices sketched above, a major product of the H-MIT REC is represented by the people influenced by the program. Three of the current faculty supervising REC projects conducted their own Ph.D. investigations in the MIT laboratory and a fourth faculty member started in the laboratory as a research engineer. Other Ph.D. students trained in the REC are now faculty conducting rehabilitation research at Boston University, the University of Michigan, the University of British Columbia, the University of Utah, the University of Minnesota, the Massachusetts General Hospital and the Orthopaedic Research Institute in Davos, Switzerland. An M.D. vice president of a major orthopaedic appliance corporation did his graduate degree in the REC. MIT/MGH are offering one of the two Advanced Rehabilitation Research Career Development Programs funded by NIDRR, providing year-long formal course work and individual research experiences to post-graduate persons trained in engineering, physical therapy and medicine. Literally hundreds of MIT students have been introduced into and contributed to rehabilitation engineering though individual research projects, design subjects, seminars and theses.

CONCLUSION

Extensive experience in the practice of rehabilitation engineering, reinforced by the unique resources of MIT, CHMC and the MGH, supports an integrated range of projects addressing musculoskeletal pathologies under the general theme of Quantitative Functional Assessment. Practical results of the H-MIT REC include enhanced understanding of the underlying pathologies, improved medical and rehabilitation processes, technological devices, and trained and experienced persons whose careers are committed to the advancement of rehabilitation technology.

ACKNOWLEDGEMENTS

The H-MIT REC has been supported since 1972 by the NIHR, now NIDRR. From 1959 until 1972 the MIT group was supported continuously by predecessor organizations including OVR, SRS and RSA. Other federal agencies who support projects complementing the REC program include NIH, NSF, and the VA. A number of private foundations have made and continue to make important contributions to both program and equipment.

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DESIGN AND DEVELOPMENT OF A METABOLIC INTERFACE TO COLLECT SELECTED MEASURES ON CHILDREN WITH CEREBRAL PALSY

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ABSTRACT

An instrument designed to allow the collection of metabolic data from subjects who can not tolerate the traditional testing protocol was constructed and validated. This equipment allows the accurate measurement of metabolic expenditure of children who previously could not be evaluated using a mouthpiece.

INTRODUCTION

Restrictive pulmonary impairments are frequently exhibited by children with neuromuscular dysfunction (2). Similarly, it has been noted that maximal aerobic power and mechanical efficiency of children with cerebral palsy is lower than normal controls (5,6). Few studies have been conducted to investigate the reasons for this decreased metabolic efficiency of the child with cerebral palsy. A primary reason for this lack of research must be attributed to the inability of this population to tolerate testing protocol.

One laboratory technique used to evaluate metabolic expenditure is indirect calorimetry. Indirect calorimetry is based on the premise that metabolism requires the use of oxygen and thus measuring this consumption provides an indirect measure of energy expenditure (7). Common testing protocols require the collection and analysis of expired air through a mouthpiece and one-way valve arrangement. Children with cerebral palsy, because of poor oral motor control and the need to periodically clear saliva from the mouth, often have difficulty maintaining an airtight seal between themselves and the laboratory instrumentation (1). Subject tolerance is an additional factor that must be considered in the collection of expired air from children with cerebral palsy. Often these subjects are not willing to give up their nasal airway to tolerate the discomfort of breathing through a mouthpiece for extended periods.

PURPOSE

The purpose of this study was to design, construct, and validate a subject/instrument interface for the collection of expired gas with individuals who, because of a motor impairment, are unable to tolerate the standard mouthpiece configuration.

DESIGN AND CONSTRUCTION

Design of the equipment developed for this study was based on the premise that many children with cerebral palsy have worn or are familiar with others who wear a helmet for protection. This concept and other factors (i.e. moveable facemask, bright colors, and decals) were integrated into the design to encourage subject acceptance.

A motorcycle helmet shell was used to facilitate development and reduce construction costs. This shell was modified with the addition of two inhalation ports (Hans Rudolph # 2600) positioned on both sides of the helmet. Expired air was collected using a large-bore one way valve (Hans Rudolph # 5800). A double-layer, latex rubber membrane provided the desired seal around the patient's neck. The moveable facemask on this helmet was unique in that it not only moved downward but also rearward, thus allowing the inclusion of a gasket to provide an airtight seal The design of the subject/instrument interface allowed the helmet to be carefully fitted to the child. The interface is airtight allowing it to be used with a variety of equipment to collect and analyze selected metabolic measures

INSTRUMENTATION

Open-circuit calorimetry has proven to be the best indirect technique to calculate oxygen consumption. With this system the subject continuously breathes ambient air as expired gas is collected and analyzed. The configuration selected for use in the validation study consisted of an airtight interface used with a

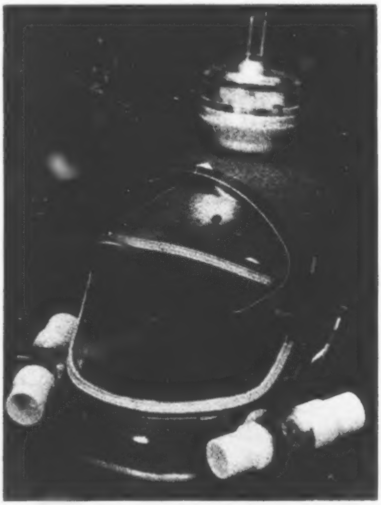

Figure 1 Subject/Instrument Interface

low flow rate (3 liters/min) flow-thru system. This low flow provided a positive pressure gradient toward the mixing chamber, ensuring the movement of heat, moisture, and expired air. Oxygen consumption ($\dot{V}O_2$) was calculated by multiplying the flow rate of the air through the system by the difference in oxygen concentrations of room air and mixed expired gas. Carbon dioxide production ($\dot{V}CO_2$) was similarly calculated (4).

VALIDATION

Subjects

Subjects for this validation study were solicited from a summer day camp program sponsored by Variety Village, Toronto, Canada. Prospective subjects were screened by the camp staff prior to acceptance into the study. A total of 13 subjects (N = 8 children with cerebral palsy; N = 5 non-neurologically involved) participated in this investigation.

Methods

Testing was conducted in the Research Laboratory of Variety Village. All testing was conducted during one session and included subject orientation and collection of resting and exercise metabolic data using both the traditional mouthpiece and subject/instrument interface. Metabolic values ($\dot{V}O_2$, $\dot{V}CO_2$, Ve) were obtained using a modified Beckman Metabolic Cart. This modification consisted of the addition of a variable-rate flow pump to draw air toward the mixing chamber. This configuration (Figure 2) allowed the normal operation of the equipment while also providing a method of obtaining a variable flow through the system.

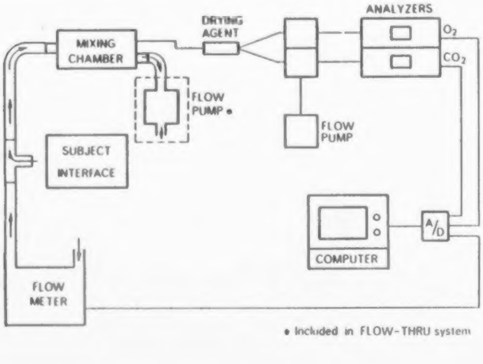

Figure 2 Modifications to Metabolic Cart

Subjects were orientated to the equipment and testing protocol. The equipment was adjusted to each subject's arm length and sitting height. Prior to data collection, subjects were allowed to rest in a seated position for 15 minutes before collection of resting values. Mouthpiece data were collected prior to interface data for all subjects and an additional 15 minutes was allowed between trials for the subject to return to a resting state. Metabolic data were collected over a five minute period (30 second averaged samples) with the mean of the last 2 samples being used as the subject's resting data.

Exercising data were collected during the performance of arm ergometry at three progressive submaximal levels of exercise intensity. To facilitate testing, the collection of subject/ instrument interface data proceeded mouthpiece data for all subjects. Intensity of work was individually selected for each subject based upon the investigator's perception of the subject's work capacity. Work loads were documented and duplicated for the second trial. Each exercise level consisted of a two minute adjustment period followed by two 30 second data collection periods. A mean of these two samples was used for data analysis. The exercise testing continued until all three levels were completed or the subject was unable to continue. Only 2 of the subjects with cerebral palsy were able to complete the third level of exercise. This was attributed to localized muscular fatigue possibly due to mechanical inefficiency and/or a subnormal blood flow to the spastic musculature during exercise (3).

Results

Measures of particular interest in this investigation included oxygen consumption (VO_2) and carbon dioxide production (VCO_2) during rest and at each of the progressive exercise stages. No observable pattern of error was observed between the mouthpiece and interface values obtained from the non-impaired and subjects with cerebral palsy. For this reason, data obtained for all subjects were combined for analysis. Validity of the subject/instrument interface was evaluated using a concurrent criterion procedure (8).

Correlations between values obtained for each experimental condition at each exercise level were high ($\dot{V}O_2$ 0.94 to 0.84: $\dot{V}CO_2$ 0.92 to 0.85) and found to be significant ($p<0.05$). These results indicate that when used in an airtight, low flow configuration, the subject/instrument interface designed for this project provides a valid method of collecting metabolic data. It is anticipated that this technique will allow the collection of metabolic measures on children who, because of their impairment, could not tolerate the mouthpiece protocol.

SUMMARY

The subject/instrument interface designed for this study, when used in a airtight, low flow configuration is a valid method to collect metabolic data on children while at rest and while performing moderate levels of physical activity. Valid measurement of metabolic efficiency of children exhibiting cerebral palsy represents a significant contribution to the field of rehabilitation. This technique will allow investigators to accurately evaluate the nutritional needs of children with moderate to severe cerebral palsy. In addition, therapists and rehabilitation engineers will be able to quantify the effects of selected rehabilitative techniques upon the energy expenditure of the child. Surgical procedures, intended to increase mechanical efficiency (e.g., tendon transfers, lengthening) can also be evaluated with a direct measure of energy consumption. Similarly, the long term metabolic effects of clinical procedures (e.g., seating, selection of walking aids) may be quantified using the interface designed for this study.

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AN APPARATUS FOR MEASURING KNEE JOINT MOTION "IN VIVO"

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ABSTRACT

A non-invasive, portable method for six degree of freedom knee joint measurement has been developed using a commercially available sensor. Software has been written to display knee joint motion in either eulerian or finite screw axis form for evaluation. Preliminary data indicate that the measurements are in the expected range for angles and displacements.

INTRODUCTION

A non-invasive, simple method for measuring the six degree of freedom motion of the knee joint "in vivo" is essential in both clinical and research settings. On the one hand it provides quantification and diagnosis of pathological movement and its rehabilitation, while on the other hand it allows a greater number of subjects to be tested performing a variety of postural tasks. In addition, a valuable comparison with the available "in vitro" data will be possible once "in vivo" data is available. Our technique offers a portable, compact system in contrast to electro-optical methods described in the literature(1,2,3).

METHODS

Our method involves measuring joint motion by placing an electromagnetic system (Polhemus Navigation Systems, Colchester, VT) consisting of a detector and emitter, on the tibia and femur. A 60 Hz sampling frequency is dictated by the detector/emitter hardware. The system's static resolution is .7 mm in position and .1 degree in angle, but its performance degrades as angular and linear velocities increase (4). This effect is due to the emitter's movement in space during multiple electromagnetic readings which are taken to fix its translation and rotation. Our expected maximum angular velocity of 120 degrees/second corresponds to an angular lag of 1 degree, while our expected maximum linear velocity of 1 foot/second corresponds to a position error of 2 mm. Most errors are expected to be below fifty percent of these maxima. These estimates were verified by simulating knee motion with a pinned hinge moving at constant velocities.

A pilot study determined the location of the least skin movement around the knee joint. On the basis of these findings an attachment fixture was designed for both tibia and femur. The tibial fixture consists of a flat plate which rests on the medial anterior surface of the tibia and is held in place with elastic straps (see figure 1). The femoral fixture consists of a clamp with padded disks which holds the condyles at the lateral and medial sections, and of an extension attached to the clamp that lies along the long axis of the bone. Both are light, rigid, and durable devices that are easily donned and doffed. The relative motion between these fixtures and the bones was investigated using biplanar x-rays. The motion of the tibial fixture was not detectable whereas the femoral fixture showed an acceptable AP shift.

The mathematical description of our system involves defining four distinct axis systems, OT, OF, OE, and OD, which correspond to the tibial, femoral, emitter, and detector axis systems respectively. The rigid body motion of the femur relative to the tibia is derived using three four-by-four transformation matrices, BFE, BED, BDT, which transform from femur to emitter, emitter to detector, and detector to tibial axis systems respectively. These three transformations are equivalent to one transformation (5) from the femur to the tibia, BFT (see figure 2). Since both emitter and detector are idealized as rigidly attached to the femur and tibia, the transformations BFE and BDT do not change once the fixtures are in place. Only the transformation between emitter and detector, BED, changes as the joint moves. This motion is further broken down to eulerian angles (sucessive rotations about the X, Z, and Y tibial axes) and displacements of the femoral origin relative to the tibia, to aid in graphical display (see figure 3). The equivalent finite screw axis for BFT was also calculated for an alternative display of the data (6).

The tibial and femoral axis systems, OT and OF, are defined as being coincident at full extension; they are also referenced to the environment: the x axes are parallel to the ground, the y axes are parallel to the wall with the z axes defined by their cross product. The origin is located midway between the centers of the femoral condyles as located using medial/lateral x-rays. These axis systems are derived from points digitized on the wall, ground, and condylar centers in the detector's axis system at full extension. The transformation matrices BFE and BDT are also derived by invoking the requirement that tibial and femoral axes are coincident at full extension i.e.

$$[BFT] = [I] = [BFE][BED][BDT]$$

An initial emitter/detector reading is taken at full extension to find [BED]; the tibial axis system has been digitized and described in the detector's axis system - i.e. [BDT] is known. Thus [BFE] can be derived in terms of the other knowns in the equation.

Data acquisition software is written for a microcomputer (Apple IIe) which prompts the user for each experimental step and interfaces with the emitter/detector hardware. Data during motion are collected and transferred to a MicroVax for post processing. Additional software relating the six degree of freedom motion about the randomly oriented emitter/detector axes to the knee axis system allows the graphical display of knee joint motion for convenient assessment.

EVALUATION

Considering the fact that the acquired data are not direct measurements of the skeletal motion of the knee, the results obtained from normal subjects were encouraging in that they were consistent with published "in vitro" data (7). A safe and consistent method for examination of knee motion disorders has been proven. A data bank on various disorders will aid in the prevention, diagnosis, treatment, and rehabilitation of knee injuries.

ACKNOWLEDGEMENTS

We thank Dr. Peter Walker for his impetus and ideas for this project. This work was supported by the Veterans Administration Rehabilitation Research and Development Service.

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Figure 1. Tibial and Femoral Fixture

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Figure 2. Axis Systems and Transformation Matrices

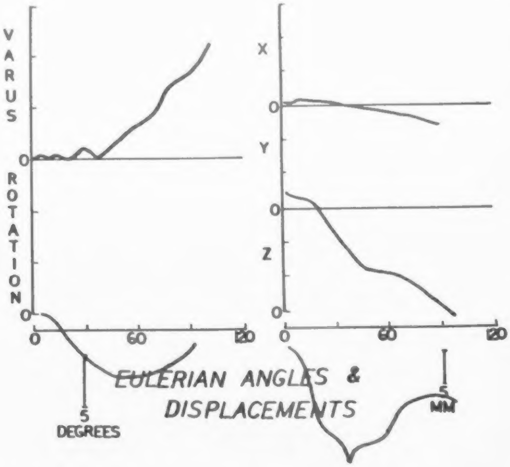

Figure 3. Computer Display of Data

MANUAL GONIOMETER SYSTEM FOR OPTIMIZING MEDIO-LATERAL HIP POSITION IN ADAPTIVE SEATING

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ABSTRACT

The incidence of hip deformities in nonambulatory children and young adults with cerebral palsy is high. In terms of its prevention and management, the windblown type of deformity is specifically an important challenge for clinicians. Proper prevention and management of windblown deformity in adaptive seating position requires that hip abduction/adduction be reliably measured before and during treatment. The goniometer described here consists of a pair of protractors, arms and blocks, and a rail. Unlike other manual goniometers, the goniometer utilizes the anterior superior iliac spines and the mid-patella as proximal and distal reference points respectively for the arms of the goniometer. It can also provide simultaneous bilateral measurements which is important for windblwon deformity. When utilized during actual fitting for customized seating, components of the seating system can be adjusted until optimal hip position is achieved.

INTRODUCTION

The use of adaptive seating and positioning for prevention of the windblown has been previously advocated.[1],[2] Proper prevention and management requires that hip abduction be reliably measured before and during treatment. The conventional manual goniometer is inadequate, because readings obtained from it are unreliable due to inability to find a suitable reference point on the hip in the sitting position for the axis of the goniometer. Also simultaneous bilateral measurement (which is important for windblown deformity) is impossible with the conventional type of goniometer. This report describes a goniometer system[3] designed to meet these requirements.

COMPONENTS AND OPERATION

The goniometer consists of a pair of protractors, arms and blocks, and a rail. Each protractor is 15 cm in diameter, made of alumnium, and has a 0 degree-90 degree-0 degree scale. The arms (goniometer arms) are 60 cm long and are made of transparent Lexan* (a polycarbonate material). Both the blocks and rail are made of aluminum. Each block measures 4 cm by 5 cm by 6 cm, and the rail is 90 cm long. Each protractor is mounted rigidly on a block. Each arm rests on the protractor and is held in place by the superior bolt which passes through the axis of the protractor (Fig.). This bolt serves as the adjustment for the goniometer arm. It is loosened to rotate the arm in a horizontal plane over the protractor and tightened to hold the arm in place to obtain readings. The range of motion is given by the position of the indicator on the scale (Fig.). Both blocks are held together by the connecting rail and fastened on the rail by the posterior bolt. Adjusting the posterior bolt allows the block (with the goniometer arm and protractor) to slide mediolaterally on the rail. The goniometer system weighs about 2.5 lbs.

OPERATION

To measure hip abduction in the sitting position, each arm of the goniometer is placed on the anterior aspect of each thigh respectively so that the long axis of the arm is in line with the anterior superior iliac spine and the mid-patella (insert in Fig.). This can be achieved by loosening both the posterior and superior bolts which then allows the blocks to slide along the rail medially or laterally and the arms to rotate horizontally. The locations of the blocks on the rail and the positions of the goniometer arms depend on the length of the thigh and the position of the respective hip joints. Measurements obtained from each joint is unaffected by the position of the other, because each joint has its own reference points. Also, rotation of the pelvis is accommodated during measurements because a distal reference point (mid patella) is used in addition to that on the pelvis itself (ASIS). Rotation of the hip does not adversely affect measurements obtained becuase the mid patella is easily identifiable in the vertical plane and its position is always a reflection of movements at the hip joint. Readings obtained when the hip is in abduction will register on the medial side of the scale and those in adduction are obtained on the lateral side of the scale (Fig.). In windblown deformity, for example, while the goniometer on one side registers the hip on the same side as being in abduction, the other goniometer registers the contralateral hip in adduction. Inter- and intra- rater reliability with the goniometer system is very high due to the type of reference points used for measurements.

USES

This goniometer system is currently used to evaluate the static position of the hip joint in individuals with cerebral palsy in the sitting position. However, it can be used for measurement of active range of abduction/adduction motion in the hip. The goniometer is used during evaluations for provision of adaptive seating system to determine individuals who have a predisposition to windblown deformity based on asymmetry in bilateral resting hip positions obtained from the goniometer.

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Pittsfield, MA 02121.

Adequate modifications in the size and location of the adductor pommel and lateral thigh supports can then be made to ensure that both hips are symmetrically positioned.

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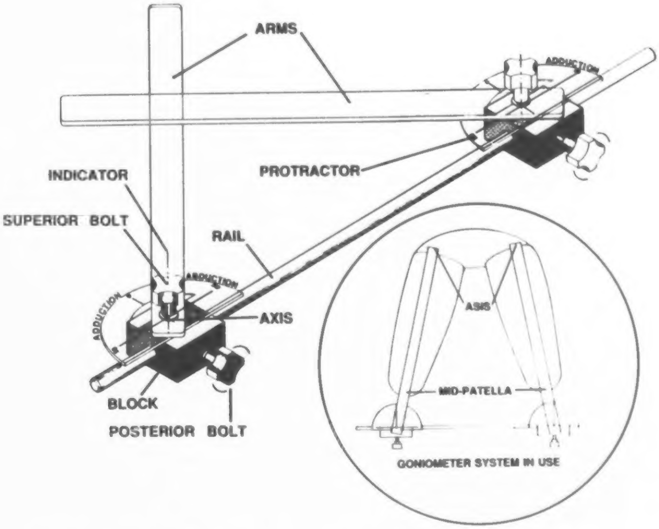
ARMS
ADDUCTION
PROTRACTOR
INDICATOR
SUPERIOR BOLT
RAIL
ABDUCTION
ADDUCTION
AXIS
BLOCK
POSTERIOR BOLT
AXIS
MID-PATELLA
GONIOMETER SYSTEM IN USE

Figure. Goniometer System. Insert shows system in use.

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AN *IN VITRO* COMPARATIVE STUDY OF TOTAL KNEE ARTHROPLASTY

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ABSTRACT

The kinematics of nine commercially available total knee arthroplasties were compared in five fresh frozen cadaver specimens. Each knee was tested in anteroposterior shear, mediolateral shear, internal-external rotational stress and active flexion-extension using the Genucom Knee Analysis System. The Synatomic design was equivalent to the normal knee in A-P shear. In M-L shear, the PCA, Lacey and Synatomic were more constrained where as the Miller/Galante was less constrained. The Synatomic and Tricon-M were more constrained in internal-external rotational stress while the Lacey, Ortholoc and Miller/Galante were less constrained.

INTRODUCTION

In the evolution of the designs of total knee arthroplasty, the semi-constrained and non-constrained TKR systems have evolved. These prostheses are designed to simulate the normal kinematics of the knee utilizing anatomical rather than the mechanical restraints. The semiconstrained total knee replacements have a cupped tibial plateau to increase joint stability and increase contact area. This tibial surface, however, increases the forces transmitted to the prosthesis-bone interface. The flat or nonconstrained devices give a greater range of motion, but reduce knee joint stability and contact area (1). Most TKR systems require the sacrifice of the anterior cruciate ligament (ACL) indicating the need for some stability to be incorporated in the design without affecting normal knee kinematics.

Our study compared the kinematics of nine commercially available total knee arthroplasties; the AGC-2000, Kinematic, Lacey, Miller/Galante, LCS, Ortholoc, PCA, Tricon-M and Synatomic. Kinematic measurements were recorded on a Genucom Knee Evaluation System which consists of a 6° of freedom electrogoniometer, a dynamometer and a computer data acquisition system. This device was developed to monitor knee kinematics *in vivo*, but has been altered for *in vitro* research with the aid of the manufacturer.

METHODS

Five intact fresh frozen cadaver specimens consisting of the distal third of the femur to the proximal third of the tibia were mounted on the Genucom. An adapter jig was developed which rigidly clamped the femur with three transfixation pins and an intermedullary rod to the Genucom test seat. Since the femur was rigidly fixed, the soft tissue compensation mode of the Genucom was disengaged. The electrogoniometer was bolted to an intermedullary rod cemented in the tibial canal. A counter weight was attached to this rod to simulate the weight of the distal leg and foot.

A Hall effect strain transducer (HEST) was mounted to the medial collateral ligament (MCL) to monitor the integrity of the knee specimen throughout the test period. Force and displacement data was monitored by the Genucom data aquisition system for anteroposterior shear from -91 to 91 Newtons at 30° of flexion, mediolateral shear from -91 to 91 Newtons at 20° of flexion, internal-external rotation due to a -6 to 6 Nm torque applied to the region of the malleoli at 20° of flexion and active flexion-extension verses internal-external rotation. Active flexion extension was achieved by a pulley system attached to the quadricep tendon.

The above tests were performed on the intact specimen after medial parapatellar incisons and after ACL sacrifice. Each test was repeated three times. Appropriate bone cuts were then made and the knee was fitted with a universal jig that would accept all nine TKR's (Fig. 1). Once a prosthesis was inserted into the specimen, towel clamps were used to close the capsule. The Tricon-M was tested twice in each specimen. The HEST continuously monitored to insure repeatability.

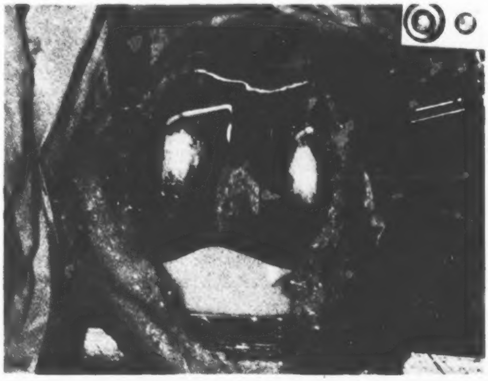

Figure 1: Knee prosthesis mounted in cadaver specimen. Note: HEST on medial collateral ligament.

RESULTS

The test results of the A-P shear, M-L shear and I-E stress tests are shown in the bar graphs of figures 2-4 respectively. This data was reproducible from specimen to specimen. The data of active flexion-extension was reproducible for the intact, open and the ACL deficient knee. However, after TKA the data did not show similar trends from specimen to specimen. It is probable that small deviations in surgical placement may account for this and thus the control of this variable is an important consideration in TKA.

A one way ANOVA was performed by type on each test category to determine if a statistical difference occurred between groups. Multiple range comparison tests were then used to determine which prostheses were statistically different from the normal specimen.

The ACL deficient knee demonstrated significantly more A-P shear at 30° of flexion than that of the intact or open specimen by 63%. No statistical differences in laxity were found between the intact, open or ACL deficient specimens with respect to M-L shear and I-E stress.

Our primary goal was to compare the various prostheses with the normal intact specimen. There was no statistical difference between the intact specimen and the Synatomic in A-P shear. All other prostheses were equivalent to the ACL deficient knee except the PCA which was more lax. In M-L shear all of the prostheses were comparable to normal except for the Miller/Galante which was more lax and the PCA, Synatomic and the Lacey which were statistically more constrained. In response to I-E rotational stress, the Synatomic and the Tricon-M were more constrained whereas the Lacey, Ortholoc and Miller/Galante rotated more than the normal knee. No other statistical differences were found.

DISCUSSION

Our protocol was designed to compare the kinematics and laxity of currently used total knee replacements. The kinematics of the semi- and nonconstrained total knee replacement are determined by the geometry of the articulating surfaces and are designed to work in conjunction with the ligamentous and secondary stabilizers of the knee joint. The ideal amount of laxity in the artificial knee design remains controversial, however, too much laxity will cause eccentric loading of the tibial component resulting in functional instability whereas not enough motion will increase stresses transmitted to the prosthesis/bone interface (2). These two extremes suggest that the ideal compromise would be a prosthesis that duplicates the normal kinematics of the human knee.

The data presented is a step in determining which features will duplicate normal knee laxity. The specimens were tested with standard clinical tests used to determine knee stiffness as well as an active flexion-extension examination. The

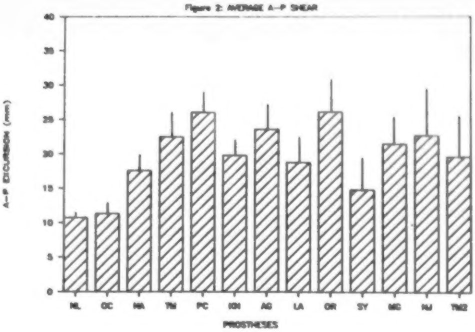
Figure 2: AVERAGE A-P SHEAR

NOTE

The devices tested have been abbreviated as follows: NL=normal, OC=open capsule, NA=no ACL, TM=Tricon-M, PC=PCA, KN=Kinematics, AG=AGC-2000, LA=Lacey, OR=Ortholoc, SY=Synatomic, MG=Miller/Galante, NJ=LCS and TM2=Second trial Tricon-M.

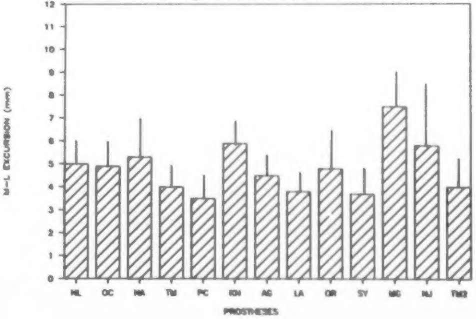
Figure 3: AVERAGE M-L SHEAR

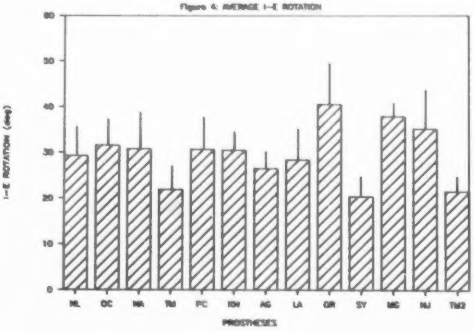
Figure 4: AVERAGE I-E ROTATION

Genucom knee evaluation system allowed us to monitor the required force displacement data of each particular test and other variables which would influence the results, such as compressive loads and varus-valgus moments. The Genucom was designed for in vivo laxity examinations. It utilizes a soft tissue compensation procedure to account for motion caused by the soft tissue envelope between the femur and the Genucom thigh clamps. An ankle clamp is also used to mount the Genucom electrogoniometer to the patient. Since the cadaver femur can be rigidly attached to the Genucom and the electrogoniometer mounted directly to the specimen, the precision of the Genucom can be improved for in vitro work. Calibration jigs were used to double check the accuracy of the electrogoniometer and the dynamometer before testing.

The tests were performed with a compressive load across the knee joint applied through the quadricep tendon in reaction to the weight of the distal lower extremity.

The data of active flexion-extension verses I-E rotation proved to be reproducible for the intact, open capsule and ACL deficient knee specimens. However, after TKA the results within each specimen were repeatable but varied from specimen to specimen. This indicates that small deviations in surgical placement such as the I-E rotational placement of the tibial component with respect to the tibial plateau may have an effect on knee kinematics. Optimum functioning of the total knee replacement is a function of proper positioning of the components to preserve normal kinematics (3). By monitoring the strain in the MCL throughout the test protocol we were able to compare joint line positioning between each prosthesis. Normal I-E positioning would not effect this output greatly and probably accounts for this variability.

This study has provided us with information on the function of the total knee replacement and provides a foundation in establishing design features for total knee arthroplasty. Part of this protocol has since been repeated in a retrospective in vivo evaluation of four total knee replacements. Results were comparable for active flexion-extension, M-L shear and I-E rotation, however the A-P stability in vivo was better. This suggests that with time other structures around the knee joint may compensate for its ACL deficiency. Further investigation is warranted.

CONCLUSIONS

Our data suggests that different condylar type knee replacements may not replicate normal knee kinematics and laxity. We found that only the Synatomic duplicated the normal knee in A-P shear and the eight others tested were more lax. In M-L shear, the Miller/Galante was less constrained while the PCA, Synatomic and Lacey were more constrained. The I-E stress test suggests that the Synatomic and Tricon-M were stiffer while the Lacey, Ortholoc and Miller/Galante were less constrained than normal. It is our goal that data of this type can be utilized in establishing the criteria for a new prosthesis which will best reproduce normal kinematics while preserving normal anteroposterior laxity.

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INITIAL EXPERIENCE WITH THE DATA GLOVE,A SEMI-AUTOMATED SYSTEM FOR QUANTIFICATION OF HAND FUNCTION

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ABSTRACT

The Data Glove ™ computer controller was compared to standard manual goniometer methods for measuring hand motion and the Polhemus™ 3-D tracker using right index finger proximal interphalangeal (middle) joints of normal volunteer hands and single-axis joint models with incorporated linear potentiometers. Initial glove single joint performance data : resolution was better than 0.5 degree for angles < 36 degrees, better than 1.0 degree angles between 36 and 54 degrees , and 2.5 degrees per flex value for angles > 54 degrees ; repeatablility / angular spread less than 8 degrees. The 3-D tracker was accurate to 0.1 degree and more expensive by a factor of 1000. Manual methods showed accuracy and repeatability ±5 degrees but were slower by a factor of 100 for single joint incremental measurments. Dynamic measurements of multiple joints simultaneously are now being performed using a modified version of the basic glove system which shows promise for clinical applications.

INTRODUCTION

The Palo Alto VAMC

The Spinal Cord Injury Center at the Palo Alto VAMC cares for the needs of approximately 500 veterans with Spinal cord in the Cervical regions which results in variable loss of the use of the arms and hand muscles. A major interest of the center is how to maintain and improve hand function in such cases. Working closely with the Hand Surgery and Plastic Surgery services , an integrated program of hand rehabilitation is developed for each patient. This may include surgical procedures designed to transfer the power of working muscles to achieve better hand function.

BACKGROUND

Current methods for evaluating hand function and documenting changes during rehabilitation are: limited in their ablilty to discern small changes ; slow and laborious ; static (resting and end range measurements) and subject to variability between examiners and test sessions. Better methods for evaluating hand function would provide a more rational basis for the development of individualized programs of management and the effect of such programs on hand dysfunction. Inexpensive, easily implimented , accurate methods for assessment of dynamic hand motions have not been available.

METHODS

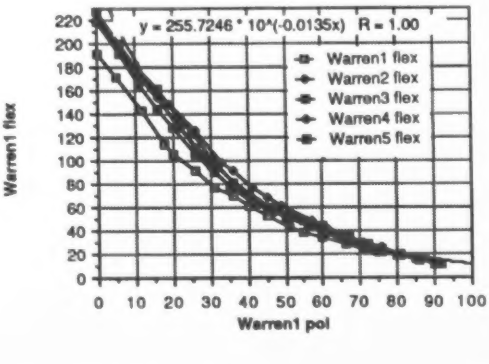
The Dataglove ™ computer controller device was evaluated as to it's potential for application to the clinical problem of hand function assessment The Data Glove ™ was compared to standard manual goniometer methods for measuring hand motion and the Polhemus™ 3-D tracker using the right index finger proximal interphalangeal (middle) joint of normal volunteer hands and single-axis joint models with incorporated linear potentiometers. Initially , the Polhemus tracker was compared to manual goniometer measurements of the single -axis "finger Joint" model . This showed the tracker to be highly accurate and repeatable within 0.1 degree, much more than the manual goniometer (± 5 degree) . It was decided to use the Polhemus device therefore as the reference standard. A mounting system for the tracker was fabricated and attached to plastic "off the shelf " distal finger joint immobilizer splints over the fingernail area of the hand in the Data glove ™ with the outer glove cover removed. The hand was rested on a foamed plastic and wood support to minimize other movement . The finger was extended fully and adjusted to the horizontal zero degree calibration of the Polhemus.

Manual goniometer measurements were made by sighting along the lateral (thumb) side of the finger and matching the angle of the goniometer to the top (extensor) surface of the digit at 5 degree intervals for the range of 0 to 90 degrees as displayed by the 3-D tracker. The subject was able to see the polhemus values displayed, and would tell the examiner (who could not) "OK" when the finger position was at the desired 5 degree incremental value , at which time the manual measurement was made. Each subject performed 5 consecutive bends for 40 total data sets.

RESULTS

Initial glove single joint performance data : resolution was better than 0.5 degree for angles < 36 degrees, better than 1.0 degree for angles between 36 and 54 degrees , and 2.5 degrees per flex value for angles > 54 degrees ; repeatablilityt / angular spreadwas less than 8 degrees. For manual methods : there was ±5 degree variability between examiners in the interpretation of the same displayed goniometer settings ; less variability was seen in the measurments taken at consecutive increments of the range (eg 0 to 5 to 10 to 15 degrees) than when readings were made in a discontinuous , random manner (20 to 40 to 30 to 45 degrees) ; accuracy and repeatability were ±5 degrees ; some examiners were consistantly better at estimating the angles than were others; and all the examiners found the 40 point series very fatiguing.

Data from "9/18 flex/pol part3"



DISCUSSION

There were initally problems with attaching the splint+ tracker consistantly to the finger tips over the glove device because of the variability in the diameter of the subjects ' fingers, however satisfactory purchase was obtained by using a combination of Velcro™for closures and adhesive tape shims between the splint and the palmar surface of the glove at the fingertip. Only two sizes of splints were avaliable at the time of the initial testing and the problems with fit would be minimized by having had a range of sizes .Variability in hand size and configuration could be significant issues in whole hand testing and a range of glove sizes should likewise be available. Dynamic measurements of multiple joints simultaneously are now being performed using a modified version of the basic glove system which shows promise for clinical applications.

CONCLUSIONS

For measurement of single joint range of motion in 5 degree increments , the Data glove™ was more accurate and faster than manual methods,and as fast as the Polhemus ™3-D tracker, but not as accurate . The 3-D tracker was accurate to 0.1 degree and more expensive by a factor of 1000. Manual methods showed accuracy and repeatability ±5 degrees but were slower by a factor of 100 for incremental measurments of the range of a single joint. A range of splint and glove sizes would facilitate more accurate fitting to the subjects'hands for easier testing.

ACKNOWLEDGEMENTS

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Photo Credit S. Fisher /NASA-Ames

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THE AVAILABLE MOTIONS INVENTORY: AN ASSESSMENT INSTRUMENT FOR PRE-VOCATIONAL INDIVIDUALS

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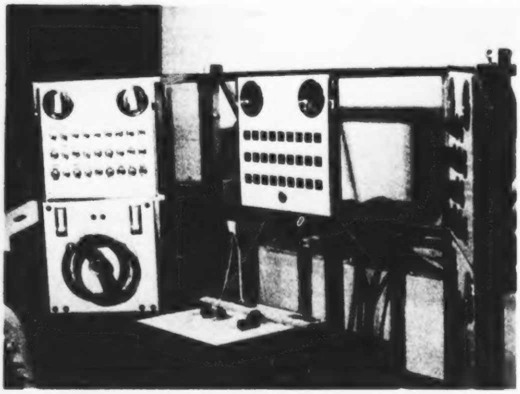
ABSTRACT

A study was undertaken to evaluate the utility of the Available Motions Inventory, AMI, to determine aptitudes of prevocational aged individuals pertinent to occupation. Established norms were extended for the population 12 through 17 years of age and analyzed. In a longitudinal study, the AMI evaluation was administered to school-aged subjects on two occasions with approximately two years between evaluations. Changes in performance were analyzed. A hypothesis that the AMI evaluation can be useful in identifying realistic occupational goals for disabled youth was proposed. The information derived from the administration of the AMI was shared with parents, educators, and the individuals themselves. The utility of such information in preparing Individual Educational Plans is to be assessed.

INTRODUCTION

Description of the evaluation system

The Available Motions Inventory, AMI, is an assessment system which analyzes physical motions which an individual can perform in order to achieve a wide range of physical tasks. It is somewhat less precise than pure anthropometric analyses but more precise in identifying specific capabilities than work sample systems. It is based on the MODAPTS system which documents very small components of physical tasks which can be assembled into an unlimited repertoire of activities.



Available Motions Inventory
Evaluation Apparatus

Evaluation apparatus

A variety of test modules are designed to be mounted on a console-shaped frame, such that they can be presented to the evaluation subject in several orientations to the subject's body. Subsections were devised to sample switch activation, settings, rate, strength, assembly of small items, response to a stimulus, and speed at reaching a required distance. All subsections of the AMI evaluation are timed except for one which evaluates the subject's strength of hands and arms.

Evaluation data analysis

The data analysis system of the AMI yields several different types of information. All results are expressed as z-scores. Scores achieved on individual items are reported. Scores for items performed at any one position are compared to items performed at other positions; this indicates the optimum orientation of work to the individual. A comparison of scores for a general class of activity is also presented.

A final type of analysis, Motion Class analysis, has proven to be useful in determining the unique characteristics of the population for which it has been utilized. It differentiates the body member (fingers, hand, and arm) which is required to perform an activity as well as the complexity of the motions required (one, two, three-dimensional, or rotary). This type of analysis allows for AMI information to be transferred to any type of activity.

Utility of the evaluation system

The Available Motions Inventory, AMI, is a recognized instrument for assessing the vocationally-related aptitudes of physically disabled persons. Data derived from the AMI has proven effective in assessing an individual's potential to perform a given task as well as to identify modifications which would enable that person to be productive in a specific work environment. Adult clients of the Cerebral Palsy Research Foundation of Kansas, Inc., CPR, have benefited from the use of the AMI. More than one hundred clients have acquired jobs which included an analysis of their AMI evaluation profiles.

In has been a consistent observation by professional staff of CPR, that disabled individuals typically develop occupational goals on a delayed schedule in comparison to their able-bodied peers. Given the difficulty of acquiring needed skills this appears to contribute another handicapping factor into their lives. Therefore, a study was undertaken to determine the applicability of the AMI evaluation to the needs of disabled youth in formulating their vocational goals, and hence, their Individual Educational Plans.

METHOD

Establishing age appropriate norms

Existing norms for the AMI included only persons 18 to 50 years of age. The AMI was administered to a group of eighteen able-bodied individuals aged 12 through 17 to determine if the norms for the younger group were significantly different than those for the adult population. Scores achieved by the younger group of subjects were compared to those already established for the 18 through 50 year old age group.

Evaluation of disabled youth

The AMI evaluation was administered to thirty disabled subjects, ages 12 through 20. The inclusion of the 18 through 20 year old subjects is to match the age range of special education students within the mandated programs of public schools. In order to determine patterns of change in physical capability of disabled young individuals, a longitudinal study was undertaken. The AMI is to be administered to the subjects on two occasions, approximately two years apart.

Analysis of test-retest scores

Changes in the performance of AMI tasks between the two evaluations were analyzed. Previous test-retest reliability studies on adult normative subjects had yielded a .85 correlation of scores. Therefore, it was hypothesized that significant changes in AMI scores, could be attributed to developmental changes. Client histories were recorded and analyzed to determine if changes could be attributed to other factors.

Application of information

Analysis of the data derived from the performance of the AMI was shared with parents, educators, and the individuals themselves. The information from the administration of the AMI was utilized in preparing the Individual Educational Plans of young subjects. A post study assessment will be undertaken to determine the perceived utility of the AMI results in formulating school and post school plans.

RESULTS

Comparison of youth/adult norms

Small but significant differences between the able-bodied youth and adults of the normative group were identified in two of the six subsections of the AMI evaluation. The rate tasks, simple rotation of controls handles, were performed more rapidly by the younger group. The adults exhibited greater hand and arm strength.

Evaluation of disabled youth

The Available Motions Inventory was administered to thirty school aged individuals. Evaluation subjects were drawn from students of the Wichita public school system, special education cooperatives, and client contacts of the professional staff of the Cerebral Palsy Research Foundation. The results of the first evaluation were shared with educational professionals, parents of evaluation subjects, and the subjects themselves. Written evaluation summaries included general definition of the subject's future occupational potential. Suggestions were included for curriculum and programming to enable the subject to attain such goals.

Re-evaluation of disabled youth

Two years following the first evaluation, a second evaluation is to be administered. These are to be completed within the year. The scores of the two evaluations of all of the subjects will be compared on an individual basis at the conclusion of the study in a detailed manner. As the second evaluations are completed scores are being compared for use in current program planning.

The scores from the second evaluation typically are very consistent with those from the first evaluation except in instances in which a major external factor affects the scores. For instance, one subject's composite scores were significantly improved on the second evaluation. This subject's primary disability was cerebral palsy; however, his eyesight was severely limited. In the interim between the two evaluations he had been fitted with a more appropriate eyeglass correction. Thus, the improved scores may be more a result of improved vision than improved physical performance.

In another instance, a subject affected by spina bifida achieved higher scores in the first performance of the AMI evaluation. The decline in scores were in the items related to fine motor control with the hands. A consultation with the staff physical therapist suggested that fine motor control could have deteriorated because the subject uses a manual wheelchair. The use of the hands for applying sufficient force to propel the wheelchair may have contributed to the increased deficit of fine motor functioning. This conclusion contributed to programming suggestions for this individual.

Case Study

The Available Motions Inventory was administered to a female student in a public school special education program at ages seventeen and nineteen. The subject is affected by cerebral palsy. She is ambulatory, although her gait is quite awkward. In addition, she has a fairly severe hearing loss. The subject's mode of communication is a simplistic form of sign language. She was fitted with a hearing aid prior to the first AMI administration. In spite of her limitations, she appeared to comprehend instructions competently by relying on lip reading and gestural instructions. This latter is an emphasized feature of the policies for administering the AMI evaluation, particularly for an individual whose hearing is impaired.

The subject displayed a characteristic which is atypical of persons affected by cerebral palsy, fine motor coordination is more competent than the performance of the larger muscle structures of the arms. When the hands are stabilized, they demonstrate reasonably well coordinated movement.

Major recommendations were submitted with the subject's performance report which focused on body stabilization by means of a positive slope cushion, armrests for lateral support, and footrests to channel energy in to useful work rather than body stabilization. Also, engineering modifications were recommended for hand stabilization.

A comparison of scores achieved on the two incidents of performing the AMI revealed the following differences:

1. Some of the strength scores were lower on the second evaluation. Since this is counter to developmental trends, a physical therapy regimen was recommended.
2. Scores on the switch tasks were lower. Scores appeared to be depressed by the subject's insistence on a more stringent degree of accuracy than is required for the AMI evaluation.

Item-by-item comparison of scores indicates that the subject's performance was generally consistent. A small positive increment in composite scores are likely due to slightly improved skills and improved comprehehsion of instructions.

CONCLUSIONS

The stability of test-retest scores on the AMI through the developmental years seems to indicate that the evaluation can be utilized to define and predict reasonable occupational aspirations on the part of secondary school aged students. Its effectiveness depends on two factors, the degree to which the evaluation data is accurately interpreted and the degree to which the information is used in the student's school, home, and trial work setting. The utility of the AMI to young subjects is also dependent on its utilization for subjects whose disability is primarily physical in nature.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the staff of the College of Engineering, Wichita State University, for its work in developing the Available Motions Inventory and its accompanying analysis system. They further wish to acknowledge the Cerebral Palsy Research Foundation of Kansas for its support of programs to improve the quality of life of physically disabled persons.

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EFFECT OF DIFFERENT SEATING ORIENTATIONS ON UPPER EXTREMITY FUNCTION IN CHILDREN WITH SPASTIC AND ATHETOID CEREBRAL PALSY

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ABSTRACT

This study was designed to determine the effect of body orientation on upper extremity function in children and young adults with cerebral palsy. Thirteen children between 8 and 26 years of age diagnosed as having spastic or athetoid cerebral palsy were randomly placed in different seating orientations (30°, 15°, and 0° of posterior inclination and 15° of anterior inclination). In each seating position the subject performed an upper extremity activity on cue. The tests were repeated in reversed sequence. It was found that mean performance times were different at all seating orientations for both types of subjects. Performance time was lowest at the 0° orientation during the retest for the spastic subjects and hightest at 15° anterior inclination during the retest for the subjects with athetosis. The results of this study show that orientation of the body in space affects upper extremity function and emphasizes the importance of positioning for maximizing upper extremity function.

INTRODUCTION

In order to maximize the individual's functional potential when positioned in adaptive seating, it is necessary to determine and understand the functional effects of factors identified as crucial to adaptive seating, and the effects of different spatial relationships between various body segments. For example, clinical studies have been conducted to demonstrate the effect of hip flexion angle in sitting on upper extremity function in children and young adults with spastic cerebral palsy.[1] The effect of orientation of the body relative to the vertical plane on abnormal muscle activity in this population has also been investigated.[2] Although the relationship is not clear, hyperactive muscle activity has been linked to decreased voluntary motor performance in individuals with upper motor neuron lesion.[3,4] Therefore, body orientation in space, by virtue of its effect on abnormal reflexes, could also affect voluntary motor function.

The purpose of this study was to measure performance time of a prescribed uppper extremity activity in four different seating orientations relative to the vertical plane in order to determine the effect of body orientation on voluntary motor function.

METHOD

Subjects

Thirteen children between 8 and 16 years of age with cerebral palsy participated in this study. Three were classified as athetoid and ten as spastic. Based on the clinical evaluation conducted by the therapist, all the subjects had fair to good gross upper extremity control, poor fine motor skills, and fair head and trunk control (on Good, Fair, Poor, No, scale). None of the children were mentally retarded and none were taking any medication.

Instrumentation

The positioning device[2] was a multiadjustable seating system with hydraulically powered independent adjustment for hip and knee postions, thigh length, and orientation in space (Fig. 1).

Upper extremity function was monitored using a system consisting of a touch-activated switch, an Apple computer, and a video monitor.[4] Ambient noise level during tests was low. Distraction during tests occurred infrequently and when it did, the trial was repeated.

Procedure

The subject was seated in the positioning device. The head and neck were supported in a neck collar and the trunk supported on the backrest so that head, neck, and trunk were in the same vertical plane. The hips and knees were placed at 90°, and the foot supported on a platform without straps.

An inclinometer placed at the backrest guided placing the subject in four seating orientations relative to the vertical plane: 0°, in which the head, neck, and trunk were in the vertical plane; 30° and 15°, in which these body segments were 30° and 15° posterior to the vertical plane respectively; and 15°A, in which the same segments were 15° anterior to the vertical plane (See Figure 1, insert).

The sequence of seating orientations tested was random and different for each subject. A rest period of five minutes after each orientation change allowed the subject to adapt to the new position. Functional activity commenced at the end of the rest period.

The subjects were instructed to move the arm from the starting position (shoulder abduction) to the midline (shoulder adduction) to touch the switch on cue from the video monitor and withdraw the hand as quickly as possible. The movement was repeated ten times. Functional performance time was calculated as the time interval between the first cue to move the arm and the tenth and final activation of the switch. At the completion of all four test orientations, they were repeated in reverse sequence in order to further evaluate both the reliability of the results for each position and the influence of time on the results.

RESULTS

The lowest mean performance time was recorded at the 0° orientation during the retest for the spastic subjects (Tab. 1) while the highest was recorded at 15° anterior inclination during the retest for the subjects with athetosis (Tab. 2). Generally, performance times were lower for the subjects having spasticity than for those with athetosis. Also, performance times during the repeat trials were lower than the initial trials for the subjects with spasticity but higher for the athetoid (Fig. 2). Analysis of variance performed on the mean performance times of the subjects having spasticity indicated a statistically significant difference ($F=63.18$, $P < 0.05$). Application of the Scheffe Multiple Range Test indicated that, at the 0.05 level of significance, the performance times obtained at 0° were different from those obtained at the other orientations; performance times at 15°, 15°A, retest 15°A, and retest 15° were not significantly different but were different from those at 30°.

DISCUSSION

The results of this study suggest that the orientation of the body in space affects upper extremity function, at least for the types of children used for this study. Performance times of subjects with athetosis were generally higher than those with spasticity, perhaps a result of prevailing abnormal involuntary neuromuscular activities and consequent movement incoordination. The differences and variability among subjects in each group emphasize the need for intragroup evaluation of research data obtained for persons with cerebral palsy.

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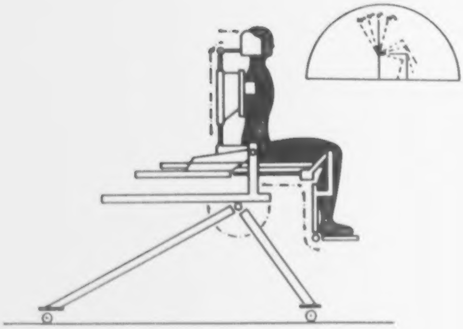

Fig. 1. Side view of the positioning device. Orientations used are shown in insert.

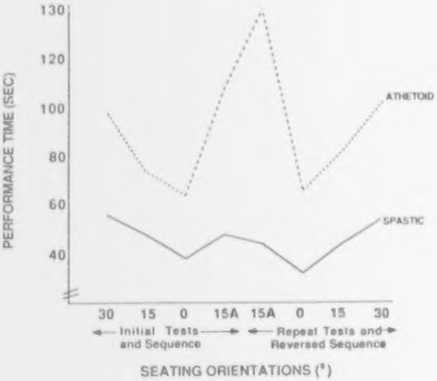

Fig. 2. Mean performance time plotted against seating orientations (15A = 15° anterior inclination).

TABLE 1 Performance Times (sec) at Different Seating Orientations for Subjects with Spastic Cerebral Palsy.[a]

	Initial Tests				Repeat Tests			
	30°	15°	0°	15°A[b]	15°A[b]	0°	15°	30°
$\bar{X}$	54.5	47.6	38.0	48.6	44.0	32.8	44.2	53.0
S	3.54	1.58	3.77	3.95	2.58	1.81	2.62	2.4
SEM	1.12	0.50	1.19	1.25	0.82	0.57	0.83	0.76

[a] N = 10

[b] 15°A = 15° Anterior Orientation

TABLE 2 Performance Times (sec) at Different Seating Orientations for Subjects with Athetoid Cerebral Palsy.[a]

	Initial Tests				Repeat Tests			
	30°	15°	0°	15°A[b]	15°A[b]	0°	15°	30°
X	96.3	71.5	64.0	106.0	130	68.5	81.8	103.5
S	2.3	1.5	1.73	1.73	2.65	1.32	2.71	1.32
SEM	1.33	0.87	1	1	1.55	0.77	1.58	0.77

[a] N = 3

[b] 15°A = 15° Anterior Orientation

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A MAGNETO-MECHANICAL 3-D SURFACE CONTOURING SYSTEM
to be used for generating soft tissue anthropomorphic data

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ABSTRACT

A three-dimensional surface contouring system has been developed which is compact, portable, simple to use, and of moderate cost. Initially, this device will be applied to the generation of an anthropomorphic data base suitable for surface replication with a computer numerically-controlled milling machine.

INTRODUCTION

A number of various commercially available systems for surface contouring were investigated. Although they employed a variety of imaging technologies, such as video imaging and sonic digitizing, they all lacked 1) ease of use and adjustability for different body surfaces 2) cost effectiveness, and 3) any means for collecting information on the material properties of the tissue. For these reasons, we pursued a prototype design for a general purpose, medium cost, direct contact, method of digitization.

METHODS

Our system may be described as a mechanical hand whose spring loaded fingers run along the surface to be digitized while maintaining a constant contact force. When a button is pressed, the host computer (IBM XT-286) stores the angular position of the fingers w.r.t. the hand via a 12 bit A/D board (Metrabyte) providing an angular resolution of .0146 degrees and concurrently locates the hand's position in space using a six degree of freedom electromagnetic sensor available from Polhemus Navigation Systems. The surface points may then be reconstructed relative to a fixed axis system. Data acquisition speed is related to the 60 hertz sampling rate of the sensor; this corresponds to 360 points/second with an six finger design. The resolution of the system, also related to the sensor accuracy, is approximately 1.5 mm (1). Distortion of the magnetic field by metal dictates that the entire device be constructed from various polymers. Information about the digitized body's compliance might be obtained by varying the constant force exerted by the fingers in subsequent digitizations and noting shape change.

The static accuracy of the sensor is .254 mm; however, since we operate the hand in a dynamic mode, estimates and measurements of dynamic error were made. The linear speed of movement, 80 mm/sec maximum, is slow enough so that positional lag errors are on the order of .127 mm. Position errors due to rotational velocity were investigated to a maximum velocity of 90 degrees/sec and were a maximum of .26 mm. Thus the cumulative error from both sources would be a maximum of 0.387 mm, less than half of our design goal of 1.5 mm.

Software was written to allow for data acquisition, processing, and geometric reconstruction of the digitized data points. Because the ultimate goal is the generation of anthropomorphic data, which is usually based on an anatomical axis system, a mathematical representation was sought which was independent of the coordinate axes imposed by the digitizing device.

A surface of arbitrary shape cannot be represented accurately by a single analytical expression. A piece-wise approach, however, not only allows for doubly-curved surfaces to be analytically represented, but also provides a simple means for insuring connectivity and smoothness (2). A variation of Coons' bicubic surface patches, with twist vectors set equal to zero, proved both versatile and practical to use. By connecting a number of surface patches together, a complex surface can be represented in a piecewise continuous manner (3).

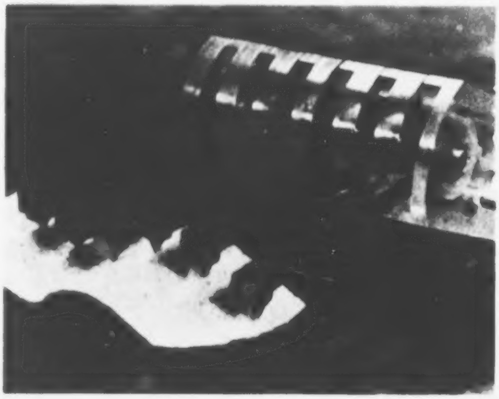

Figure 1. Hand Component

SOFTWARE

The software itself, written in Microsoft FORTRAN and Assembler, was divided into four segments:

- The first section provides the user interface, and controls data taking. The code which handles the actual interface to the A/D board and electromagnetic sensor is written in Assembler to achieve maximum speed and versatility.

- The second segment of code is responsible for the organization of the data; recurrent data points are eliminated, and the remaining data points are arranged into a form which relates the numerous passes of the digitizing wand over the surface.

- The third subroutine represents the bulk of the actual mathematics - the 'number crunching' required to spline a smooth curve between the sucessive points, and to insure connectivity between multi-patch surfaces.

- The fourth and final routine is the output stage - it provides an interractive interface which allows the user to specify the display orientation and viewing angles. The IBM Enhanced Graphics Adaptor and Color Graphics Monitor provide the display medium.

Currently under development is a fifth software module which will ultimately format the output data for input to a numerically controlled milling machine, which will replicate the contoured surface.

ACKNOWLEDGEMENTS

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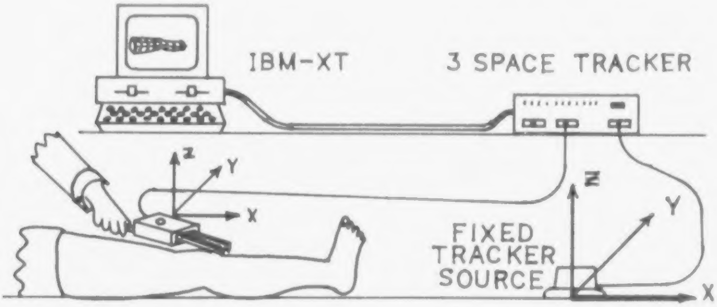

Figure 2. System Schematic

ANALYSIS OF COMPRESSION, SHEAR AND SURFACE TENSION ON SEAT CUSHIONS

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ABSTRACT

Indentation-Load-Deflection test using Instron Machine was performed to study the support characteristics of polyurethane, viscoelastic, lamina and ROHO cushions. Load-deflection data was recorded using an industrial standard 8 inch diameter indentor(1) and a 7 cm diameter indentor to simulate anatomical loading. Vertical spring constant, compression load, and shear as well as surface tension of the cushions were determined from the load-deflection data. The values obtained were used in comparing the four types of cushions and characterizing local loading on the cushions in areas of bony prominences. The results will be useful to aid in the design and prescription of seat cushion for wheelchair seating.

INTRODUCTION

Cushion support is critical for seated patients in preventing pressure sores and reducing the occurrence of further seating induced complication. However, selection of a suitable cushion for individual cases is seldom simple and straight forward. The structural and material properties of cushion as well as interaction between body weight loading and cushion are important determinants for the mechanism of load transfer of the supportive medium.

It is well known that the support characteristics of foam cushions are dependent on the compression and shear values of the material, as well as the "hammock" effect created by tension in the top surface. To study this phenomena, ILD data was recorded using an industry standard 8" circular indentor and a 7 cm circular indentor through the Instron Machine on cushions. The smaller indentor was used to simulate anatomical loading and to understand local effects on the cushion in areas of bony prominences where the large indentor can not resolve local changes in support characteristics. In addition, the ILD study was repeated for both indentors with the circular section of foam beneath the indentors completely cut free from the main body of the cushion. Therefore, the compression effect on the loaded cushion was seperated from the shear and surface tension, and the data from the ILD test were analyzed. A 3"-thick polyurethane foam, 3"-thick viscoelastic foam, 3"-thick lamina foam and 4"-thick high profile ROHO were used in this study. Since the structure of the ROHO is different from that of the foams, ILD data of ROHO was only recorded using the 8" and 7 cm indentors through the Instron Machine. The ILD test of the ROHO was repeated for different levels of applied inflation pressure inside the ROHO.

The purpose of this work was to measure and compare the vertical spring stiffness and mean deflection pressure at the cushion-indentor interface for the four typical seat cushions. The compressive, shear and hammock effects on the loaded cushions were also studied for the foams.

METHODS

The four types of cushions for this study included polyurethane foam, viscoelastic foam, lamina foam and high profile ROHO as shown in TABLE 1.

To conduct the ILD test, an 8 inch and a 7 cm diameter circular indentors were made of plywood 1/2 inch thick with 1/16" radius along the edge. At the top of the indentors, plywood 2 inches in diameter and 7/8 inch thick was cut and secured from center of the indentors. The small circular plywood was attached to a grip of the cell of Instron instrumentation.

The ILD test and data collection were directly from the Instron Universal Testing Instrument Model 1123. The compression mode of the machine was used to measure load at the specified cushion deflection under the indentors. The data were recorded with the chart recorder.

All cushions were subjected to a 24 hour conditioning cycle at room temperature 75^{0}F conditions prior to a test. The ILD test consisted of measuring the load necessary to maintain the cushion deflections under indentors for one minute. The loads were sampled at 5% to 65% cushion indentation with a 5% indentation increment. The deflection rate was set to 50 mm/min. For each test, three repeated measurements were performed with each measure conducted on a 24 hour conditioning cycle, and the data were obtained from the mean value of the three repeated measures.

Load-deflection data for each cushion was recorded using the 8" and 7 cm indentors . In addition, the load-deflection data was repeated for both indentors with the circular section of foam beneath the indentors completely cut free from the main body of the foam cushion.

The vertical spring stiffness of the cushions were determined from the slope of the load-deflection curve at 25% and 65% deflection resulting from ILD testing. The mean deflection pressure was defined as load divided by contact area of the indentors.

The load of load-deflection data, sampled from the ILD test on cushion, consisted of compressive, shear and hammock forces. The compressive force was obtained directly from the load-deflection data on the circular section of the foams. Sum of the shear and hammock forces was equal to subtraction of the compressive force from the total load. Ratio of the sum of shear and hammock forces to the total load was used to specified the effect of shear and hammock on the support characteristics of foams.

ANALYSIS OF COMPRESSION

For the ROHO, ILD test was conducted on three different inflation levels of 10, 20 and 30 mmHg inside the cushion. The effect of deflection of indentor loading on changing internal pressure of the ROHO were also studied.

RESULTS

In the ILD test, all the cushions showed load relaxation with time after a sudden deflection. The load relaxation at 25 and 65% deflections are shown in Fig. 1 and 2 for the cushions with 8 inch indentor. In these figures the rapid initial change and continued slower relaxation of the load can be seen. The load approached an equilibrium state at one minute after the deflection. The viscoelastic foam shows the largest drop of the initial load at time interval from 0 to 6 seconds, followed by the lamina foam, then the polyurethane foam and ROHO. The 7 cm indentor test show less change in initial load compared with the 8 inch indentor. In the Fig. 2 the initial load and load change for the ROHO is increasing with the increased inflation pressureinside the ROHO.

Change of the pressure inside the ROHO is plotted in Fig. 3 against the deflection with 8 inch indentor for the initial inflation pressure at 10 , 20 and 30 mmHg levels. The inside pressure is increased to 30, 44 and 57 mmHg respectively. For the 7 cm indentor, however, no change or less than 30 mmHg change was found for the deflection increased up to 65% at the three inflation levels.

The total load recorded from the ILD testing are plotted in Fig. 4 and 5 for cushion against the specified deflection. The results of vertical spring constant with 8" indentor indicate a decreasing stiffness in order from the lamina (56.6 Kg/cm), polyurethane(14.7 Kg/cm), ROHO(8.6 Kg/cm) to the viscoelastic cushion(7.24 Kg/cm). For the 7 cm indentor, the spring constant is decreasing in order from the lamina, polyurethane , viscoelastic to the ROHO. The stiffness of the foam for 8" indentor are approximately 3.5 times that for 7 cm indentor. The ROHO for the 8" indentor is approximately 30 times that for the 7 cm indentor.

The mean deflection pressure, which is calculated as the load divided by the area of 7 cm diameter indentor, is plotted in Fig. 6 for the foams and the ROHO with 20 mmHg inflation pressure against the specified deflection. Within 5% to 20% deflection range, the data indicate an increasing mean deflection pressure in order from the viscoelastic, ROHO, lamina to the polyurethane. With the deflection range increased above 20%, the pressure of the lamina is strictly higher than that of the polyurethane and the pressure of the viscoealstic is higher than that of the ROHO.

The mean deflection pressure is decreasing with an increase of indentor size for the foam. For the three foam cushions the mean deflection pressure resulting from the 8" indentor are found to be nearly half of the 7cm indentor.

TABLE 2 shows fraction of the compressive force in the total load for the foams with both 8" and 7 cm indentors. The results indicate that the fraction is decreasing with an increase of foam deflection.

For the 8" indentor, within 25 to 65% deflection, the compressive force accounted for about two-thirds of the total load; the sum of shear and surface tension accounted for the remaining one-third of the total load on the three foams. However the compressive force accounted for only about one-third of the total load and about 70% of the total load was attributed to the shear and hammock forces for the 7 cm diameter indentor.

Table 1

Four Cushions Used in the Experiment

TYPE	COMPANY	DIMENSION (inches)	COMPOSITION
Polyurethane foam	Everest & Jennings	16 X 16 X 3	low density polyurethane
Viscoelastic foam	Specialty Composites	16 X 16 X 3	medium density urethane
Lamina foam	Scimedics	16 X 16 X 3	bilayer, high/ extra high density poly-urethane
Air floatation	ROHO	16 X 16 X 4	multiple air-filled rubber bladders on single rubber base

Fig. 1

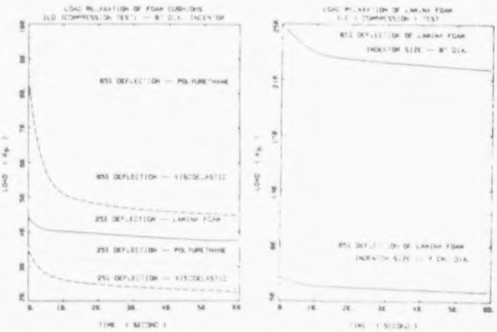
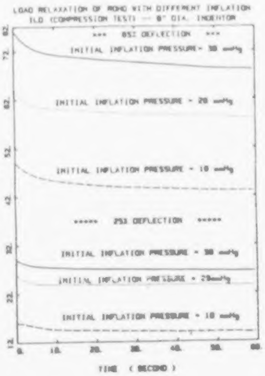


Fig. 2



ANALYSIS OF COMPRESSION

Fig. 3

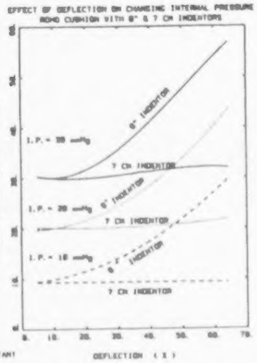
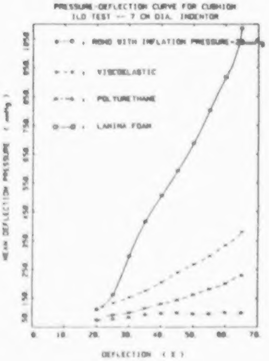


Fig.6 *b*



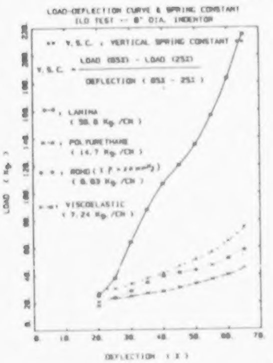
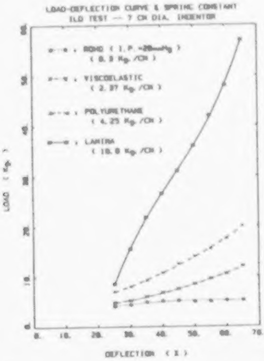


Fig.4

TABLE 2 FRACTION of THE COMPRESSIVE FORCE IN TOTAL LOAD

	8" INDENTOR			7cm INDENTOR		
	VISCO.	POLYURE.	LAMINA	VISCO.	POLYURE.	LAMINA
DEFLECTION (%)						
5	0.88	0.87	0.96	0.62	0.64	0.92
10	0.78	0.78	0.96	0.54	0.46	0.86
15	0.73	0.73	0.86	0.44	0.44	0.86
20	0.7	0.69	0.74	0.36	0.38	0.75
25	0.65	0.67	0.75	0.32	0.36	0.59
30	0.64	0.64	0.75	0.33	0.34	0.35
35	0.62	0.63	0.66	0.32	0.33	0.28
40	0.63	0.62	0.6	0.32	0.31	0.25
45	0.62	0.62	0.59	0.33	0.29	0.24
50	0.6	0.62	0.59	0.32	0.29	0.23
55	0.6	0.62	0.58	0.31	0.28	0.24
60	0.6	0.63	0.61	0.3	0.29	0.26
65	0.6	0.63	0.65	0.28	0.31	0.27

Fig. 5



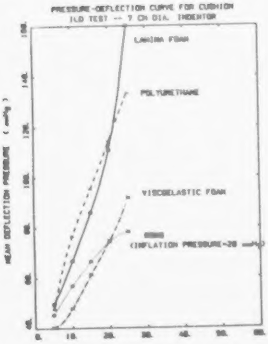


Fig. 6 *a*

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ACKNOWLEDGEMENT

This work was supported by NIHR Grant #G00-83-00072 at the University of Virginia Rehabilitation Engineering Center, P.O. Box 3368, University Station, Charlottesville, Virginia 22903. Phone (804) 977-6730.

DIFFERENCES BETWEEN BACKREST/SEAT SURFACE ANGLE AND ANATOMICAL HIP FLEXION ANGLE IN ADAPTIVE SEATING

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ABSTRACT

This study was designed to determine the relationship between the anatomical and mechanical hip flexion angles in children with cerebral palsy. Mechanical hip flexion angle was measured using inclinometers placed on the backrest and seat surface of the seating system while anatomical hip flexion was measured using an electric goniometer designed to measure anatomical hip flexion angle. By altering the mechanical hip flexion angle and recording changes in the anatomical hip flexion angle it was found that differences existed between these two angles and that in the acute range of anatomical hip flexion, a significant amount of apparent change in anatomical hip flexion angle was due to a reversal of the lumbar lordosis.

INTRODUCTION

Mechanical hip flexion angle (MHFA) is the angle between the backrest and the seat surface of a seating device. The anatomical hip flexion angle (AHFA) is the angle between the vertical plane of the pelvis and the long axis of the femur. This study is designed to measure AHFA at specific and known MHFA in order to determine the relationship between MHFA and AHFA in both normal and children with cerebral palsy.

METHODS

Subjects

Eighteen children between the ages of 4 and 8 particiapted in this study. This included 6 normal children and 12 who were diagnosed as having cerebral palsy. Based on the intensity of tonal involvement 6 were classified as mild and 6 severe. None of the children with cerebral palsy had any fixed contractures or dislocations. All were nonambulatory and required the use of adaptive seating devices for upright positioning.

Materials and Equipment

AHFA was measured by an electric goniometer specifically designed for pediatric use and to monitor changes in true hip flexion angle independent of changes in the low back (1) (Fig. 1). Electrical output from the goniometer was processed through an analog-to digital converter and by computer software. The position of the hip joint (degrees of motion) was displayed on a video monitor. The instruments reacted to changes in the static position of the goniometer and made appropriate change in the AHFA display every second.

The positioning device consisted of a backrest and seat surface both of which had hydraulically powered independent adjustment for angle of inclination (Fig. 2). A pair of inclinometers located on the backrest and seat surface were used to measure MHFA.

Data Collection

Each subject was placed on the positioning device so that the feet were supported on the foot platform and the ankle and knee at 90° of flexion. A lap belt was attached and located at the middle of the proximal third of the thigh so that the belt made no contact with any aspect of the pelvis. A four-point support chest panel was applied to approximate the trunk to the backrest and provide anterior support to the trunk. A head support was also applied.

The inclinometer located on the seat surface provided information on the inclination of the seat surface which was maintained at 0° throughout the data collection. By monitoring the second inclinometer, the backrest, was randomly placed to provide 8 different MHFA of 60, 70, 80, 90, 100, 110, 120, and 130 degrees. The AHFA was simultaneously recorded at each position. This sequence was reversed in order to obtain a second series of measurements. The average AHFA for each corresponding MHFA was computed from the two sets of recordings. The mean AHFA values for each MHFA was computed for all six subjects of each group.

RESULTS

The mean range of AHFA obtained from the normal subjects was from 74 to 118 degrees for the 60-130 degree range of MHFA that was selected (Fig. 3). For the mild and severe groups, a range of AHFA of 88 to 123 degrees and 93 to 135 degrees respectively was obtained. The largest discrepancy between MHFA and AHFA (33 degrees) was obtained in the severe subjects at the more acute MHFA of 60°. The largest discrepancy between MHFA and AHFA for the mild and normal groups (28 and 14 degrees respectively) was also obtained at the same MHFA of 60°. Generally, the difference between MHFA and AHFA decreases as MHFA increases up to about the 100 degree MHFA position for normals and 120 degree position for the mild group and thereafter increases. However, for the severe subjects, a difference between MHFA and AHFA exists for the range of MHFA positions used in this study but is least at the 130 degree MHFA position.

DISCUSSION

The results of this study show that, although related, hip flexion angle and the angle between the backrest and seat suface are not equal in most seating positions. This holds true even in normal children of the same age. Therefore, the hip flexion angle of the child in the seated position should not be described as the angle between the backrest and seat surface or the angle of inclination of the backrest. In all three groups of subjects, the anatomical hip flexion angle was larger than the mechanical hip flexion angle from the acute flexion positioning through the 90 degree MHFA position perhaps due to restrictions in anterior flexion of the pelvis imposed by the anterior and posterior pelvic structure including the hamstrings. This suggestion is supported by lower AHFA which were obtained when the knee flexion angle was decreased from the 90° position used in the study to 60 degrees in two mild subjects. Posterior pelvic restrictions is more critical in the mild and severe groups where abnormal extensor activity also limits the anterior flexion of the pelvis and allow only reversal of the lumbar lordosis when the backrest is inclined anteriorly.

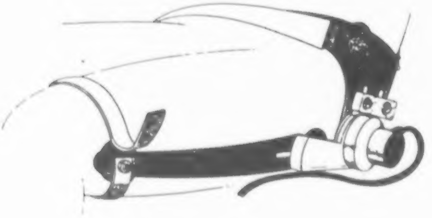

Fig. 1. Electric goniometer in use.

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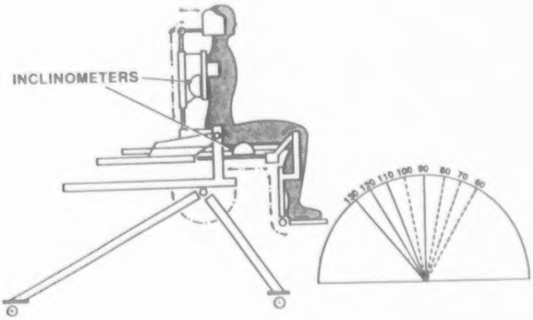

Fig. 2. Positioning device. Mechanical hip flexion angles used are shown in insert.

ACKNOWLEDGEMENT

This project was funded in part by the National Institute of Handicapped Research through a subcontract from the University of Virginia, Rehabilitation Engineering Center (Grant No. G008300072).

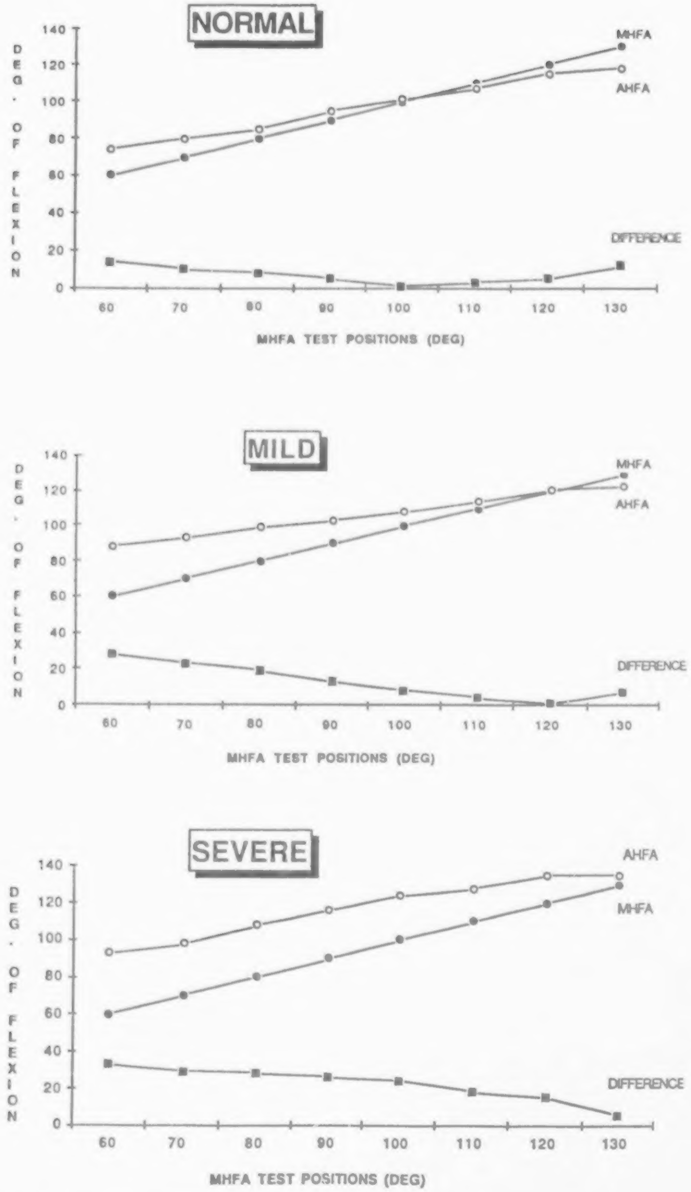

FIG.3. Mean anatomical hip flexion angle (AHFA), mechanical hip flexion angle (MHFA), and the difference between AHFA and MHFA in the three groups of subjects.

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DEVICE FOR QUANTITATIVE POSITION AND MOTION ANALYSIS

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ABSTRACT

A motion analyzer to quantify a persons available range of motion has been designed and fabricated. Although the analyzer is being used for upper extremity motions in driver assessment, the device can be used for any application calling for location of points in space. The point to be located is contacted with the end of a wand that consists of three telescoping sections of tubing. Each axis is instrumented with optical shaft encoders and digital signals three encoders are connected to an interface card in an IBM PC. The signals are manipulated and interpreted in a module of a menu-driven program written in the C language. The computer prints out the range of motion data in graphical form. The device appears to have a high potential in assessment of disabled drivers.

INTRODUCTION

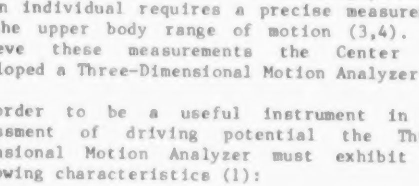
A successful assessment of the driving potential of an individual requires a precise measurement of the upper body range of motion (3,4). To achieve these measurements the Center has developed a Three-Dimensional Motion Analyzer.

In order to be a useful instrument in the assessment of driving potential the Three-Dimensional Motion Analyzer must exhibit the following characteristics (1):

1. The effort required to move the motion analyzer must be around a 1/4 of a pound.
2. The resolution of the motion analyzer must be about 1/4 of an inch in any direction.
3. Computer based. A computer is necessary to collect and analyze the data.
4. The Three-Dimensional Motion Analyzer must be simple to operate. It must be small in size.

Implementation

The implementation of the Center's Three-Dimensional Motion Analyzer consists of a 5 1/2 by 5 1/2 by 4 inch box, not including the wand. (See photograph 1) The mechanics of the Three-Dimensional Motion Analyzer consists of a universal joint to which the wand is attached.



The wand is an extensible titanium tube consisting of three telescoping sections. The end of the wand is free to move in a spherical volume.

A steel cable is inside the wand. The steel cable goes through the universal joint and onto a spring reel. The spring reel is used to cause the extensible tube to recoil when it is released by the client. It also lessens the force experienced by the client. The spring reel is connected to a 512 count Hewlett Packard Optical Shaft Encoder via a timing belt. The phi axis of the universal joint is instrumented directly with 1024 count Hewlett Packard Optical Shaft Encoder. The theta axis of the universal joint is geared through a timing belt to a 512 count Hewlett Packard encoder.

The Three-Dimensional Motion Analyzer is part of the Computer-Assisted Driver Assessment System (CADAS) that the Center has developed (see photograph 2). The computer system consists of an IBM personal computer with a number of driving related tests, Three-Dimensional Motion Analyzer being one of these (2). A shaft encoder interface board accepts the signals from the Three-Dimensional Motion Analyzer. The shaft encoder interface board has three 24 bit binary counters. The shaft encoder interface board also senses changes in direction by observing the phase relationship of the optical shaft encoders' signals (5).

The system has a calculated resolution in the r parameter of about 0.001 inches and the theta parameter of 0.012 inches and the phi parameter of 0.125 inches. These figures are based on a calculated 8 foot extension of the wand. Resolution is improved for smaller deflections.

Position data are read in and then stored by the software written in the C programming language. The computer software performs the necessary mathematics to convert from spherical coordinates to cartesian coordinates. Software was developed with extensive interviews of the Center's driver trainer (3) and occupational therapist (4).

Range of motion data is stored on floppy disk for future reference. Sample printouts for the range of motion data appear in figure 1. It was found that the data was best presented graphically in an overhead view and a profile view as well as a list consisting of the exact location of each point. The points and graphs are in cartesian coordinates with the origin at the point on the floor directly below the Motion Analyzer. The software makes all additional coordinate translations so that the data appear correct on the printout. This graphical format allows the driver trainer or vehicle modifier to superimpose scale drawings of steering wheels and driving devices on the printout so that proper fit can be determined.

PROBLEMS

There have been several problems experienced during implementation of the Three Dimensional Motion Analyzer. Most problems have been in the mechanical implementation of the device. We have found gearing up the r axis was not necessary; high resolution encoders can do the job without gearing.

No level wind was provided with the spring reel, thus a problem occurs when the cable rewinds onto the reel. The cable sometimes stacks up on the bottom or the top of the drum causing the apparent radius of the spring reel to change.

Another problem with the Three-Dimensional Motion Analyzer is that the wand return cable travels through the universal joint, but does not travel through the exact center of the joint, thus the apparent value of r changes with the value of phi.

Our first attempt to instrument the various axes used pre-built encoders, which called for a shaft to be inserted into the encoder body. In several cases we were never able to get these encoders to work even though they were mounted for us by the manufacturer. We found that Hewlett Packard kit type encoders are much more acceptable.

RESULTS

Although there have been several problems with Three-Dimensional Motion Analyzer, in general it has been a successful and useful device. At the time of this writing operational experience is being gained with the Three-Dimensional Motion Analyzer and may result in further refinements. Problems have been minimized to the point where it can provide data and thus it appears to be a useful tool for driver assessment.

ACKNOWLEDGEMENTS

I would like to thank the National Institute on Disability and Rehabilitation Research (NIDRR) of the Department of Education for support of our project (supported by cooperative agreement G0083C0097). Also, I would like to thank the clerical staff and technical staff at the Center for all the help and support they have provided during this project. I would especially like to

```
                              LIST OF POINTS

     Date 03-24-87  Time 16:37

   # Coordinates (inches)  Name of point
        X       Y      Z

   1   2.7L   51.2   45.4   Bridge of nose
   2   3.3L   54.1   50.7   Top of head
   3   8.3L   55.8   38.5   Acromian process of left shoulder
   4   3.0R   56.4   39.4   Acromian process of right shoulder
   5   6.0L   34.8   21.2   Left knee
   6   4.2R   35.4   21.2   Right knee
   7   5.7L   30.9    1.8   Tip of left foot
   8   3.3R   31.2    1.9   Tip of right foot
   9   5.3L   38.7   15.9   L thigh (underside @ edge of cushion)
  10   1.4R   37.6   16.1   R thigh (underside @ edge of cushion)
  11   7.3L   32.0   25.2   Left shoulder flexion - 45 degrees
  12   8.7L   29.8   40.0   Left shoulder flexion - 90 degrees
  13  13.6L   74.0   57.6   Left shoulder flexion - maximum range
  14   7.1R   47.7   36.1   Hor. adduction to across midline - L.
  15  19.0L   56.5   39.0   Sh. abduct L. (elbow flex to 90 deg.)
  16   9.4L   54.5   34.7   Shoulder extension w/ elbow flexed L.
  17   2.1L   53.5   32.4   Left hand to chest at midline
  18   6.6L   55.8   39.8   Left elbow flexion
  19  11.7L   36.1   21.3   Left elbow extension
  20  10.1L   39.3   31.5   L. wrist extend (forearm @ neutral)
  21   1.4L   41.6   30.2   Left wrist flex (forearm @ neutral)
  22   6.2R   33.7   26.6   Right shoulder flexion - 45 degrees
  23   5.0R   31.2   39.5   Right shoulder flexion - 90 degrees
  24   9.3R   77.9   54.6   Right shoulder flexion - max. range
  25  14.8L   57.8   37.2   Hor. adduction to across midline R.
  26  14.3R   60.7   40.0   Sh. abduct R. (elbow flex to 90 deg.)
  27   7.4R   56.4   26.9   Shoulder extension w/ elbow flexed R.
  28   2.6L   53.7   33.3   Right hand to chest at midline
  29   4.7R   57.7   40.8   Right elbow flexion
  30   4.0R   34.8   24.0   Right elbow extension
  31  10.2R   38.8   30.9   R. wrist extend (forearm @ neutral)
  32   1.3R   39.4   30.1   Right wrist flex (forearm @ neutral)
  33   2.3L   47.7   37.5   Head flexion
  34   1.8L   67.7   44.4   Head extension
  35  10.6L   51.4   40.4   Head lateral flexion to left
  36   8.1R   54.9   40.0   Head lateral flexion to right
```

Figure 1.a.

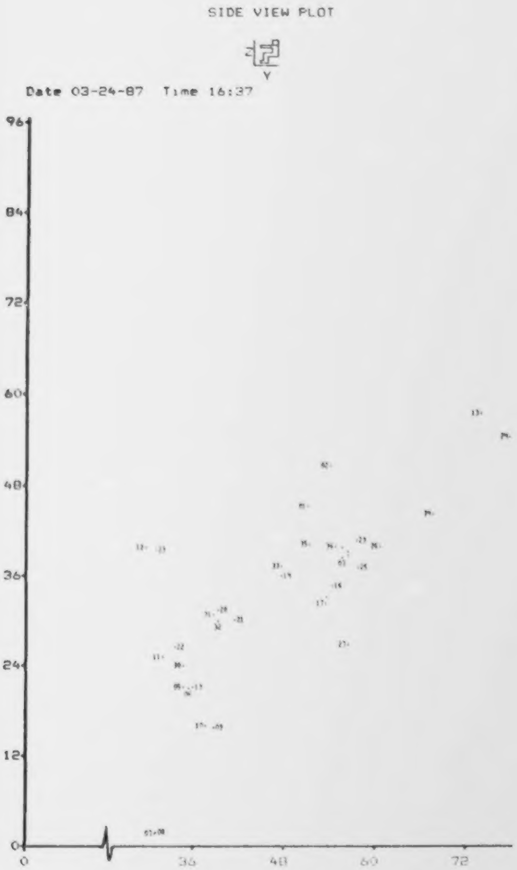


Figure 1.b.

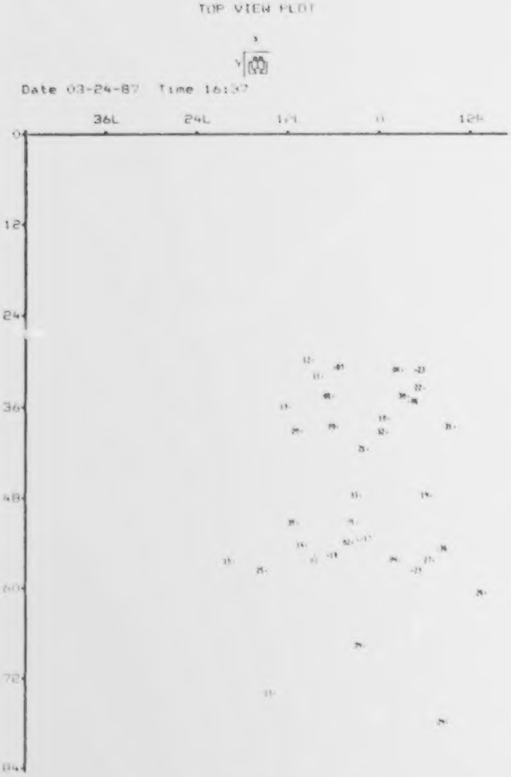


Figure 1.c.

thank Ed Irwin who developed the original concept for the Three-Dimensional Motion Analyzer, Gary Culp, who wrote the software and John Pineau who redesigned and fabricated the mechanical portions of the Three-Dimensional Motion Analyzer.

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4. Formal and informal interviews with Kathleen Nilsen, former Occupational Therapist for Louisiana Tech Center for Rehabilitation Science and Biomedical Engineering.

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AN IN VIVO EVALUATION OF FOUR TYPES OF TOTAL KNEE ARTHROPLASTIES

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ABSTRACT

Thirty-four patients who had undergone forty-two total knee arthroplasties during the past five years were examined on the Genucom Knee Evaluation System. This group represents an equal number of PCA, Variable Axis, Tricon-M and Anametric total knee replacements. Ten normal subjects were used as a control group. Each patient was tested for anteroposterior stability, medial/lateral stability, varus/valgus stability, internal/external rotation at 80° and 20° of flexion and internal/lateral rotation over the active range of motion.

At 30° of flexion the variable axis was 50% more constained than the normal knee in anterior/posterior laxity. The Anametric and the Variable Axis were more lax in varus/valgus testing than the normal knee by 85% and 75% respectively. No other statistical differences were found.

INTRODUCTION

Knee motion has been studied extensively in normal patients, those with ligamentous injuries, and in those who have undergone arthroplasty. The Genucom Knee Evaluation System is a noninvasive device which provides quantitative measurements of knee laxity. It provides force versus displacement data in flexion/extension, varus/valgus, internal/external rotation, medial/lateral, and anterior/posterior planes. This in vivo study was undertaken to determine how closely four different semi-constrained arthroplasties conformed to normal knee kinemetics.

MATERIALS & METHODS

Patients who were one to five years post-total knee arthroplasty were available for examination. Four prostheses were studied; the Anametric, the Variable Axis, the PCA, and the Tricon-M. All patients were evaluated using the Hospital for Special Surgery Knee Evaluation scale.

A total of forty-one knees in thirty-three patients were examined. The test group conisted of eleven men and twenty-two women. Ten control knees were also examined to form a control group.

All arthroplasties were implanted at MCHV by or under the direction of two surgeons. Post-operative management was also consistent in all cases. One examiner performed all tests to eliminate inter-tester variation.

The Genucom Knee Analysis System was used to test each subject. This system consists of an electrogoniometer, a dynamometer and a computer. This device allows for uniformity of patient positioning. All patients were evaluated by standard testing methods as follows:

Lachman: Anterior and posterior displacement was measured at 30° of flexion and neutral rotation. The anterior/posterior displacement between -91 and +91 Newtons was determined.

Medial/lateral Drawer: With the knee in 20° of flexion and neutral rotation, medial and lateral forces were applied to the tibia. The displacement was measured from -91N to +91N.

Varus/Valgus: Varus/valgus angulation at 20° of flexion from -12 Nm to +12 Nm was recorded. Displacement was measured as degrees of tibial rotation about an axis perpendicular to the long axis of the tibia.

Rotation: With the knee in 20° and then 80° of flexion, internal and external rotation moments were applied at the ankle. Degrees of displacement were measured from -5 Nm to +5 Nm.

Screwhome: Active flexion/extension was performed by each subject and internal/external rotation was measured to determine the screw home mechanism.

The SPSSx statistical software package was utilized to determine statistical difference within each test. Analysis of variance was performed to determine if statistical differences occurred between prostheses. If a difference did exist, each prosthesis was compared to the normal knee using the Duncan and least significant difference multiple range comparison tests.

RESULTS

All patients were able to cooperate for the examination. Some experienced discomfort with one or more tests. If the limits of force or moment could not be achieved, the data was eliminated. During testing, all subjects were asked to keep their quadriceps relaxed. In this way, passive stability due to ligaments, soft tissues and joint contours was measured and the effect of variable muscle activity minimized.

The Lachman data obtained in this study is shown below in Table 1. The Variable Axis prosthesis was significantly more constrained than the normal knee to anteroposterior translation at 30° of flexion (p 0.05).

The mediolateral drawer data is presented in Table 2. No statistical differences occurred between the prosthesis.

Varus/valgus displacement has been measured by other authors in varying degrees of knee flexion. Clinically this test is most often performed in 20 degrees of flexion. With varus/valgus stress both the Variable Axis and Anametric knees showed more laxity more than the normal knee (Table 3).

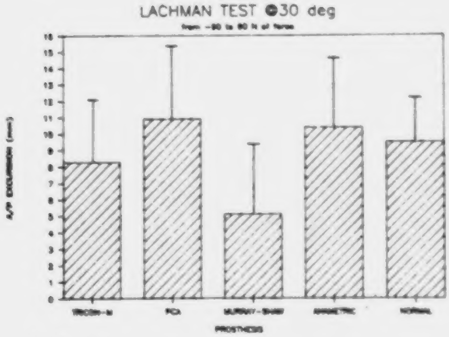

Table 1.

Cadaveric studies of I/E rotation have been performed by Wang and Walker (1) and Markoff et al (2). Rotation was found to be least in full extension and gradually increased to 20 degrees of knee flexion and greater. During testing it was felt the femur was rotating within the soft tissue envelope of the thigh at 20 degrees. All subjects were also tested at 80 degrees in an effort to decrease this variable (Tables 4 & 5).

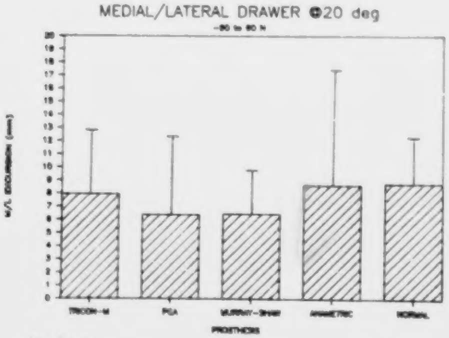

Table 2.

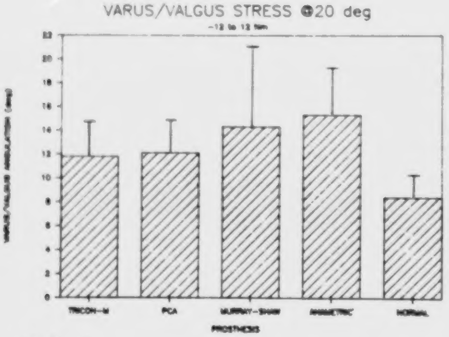

Table 3.

No statistical differences could be found between normal and replaced knees at either the 20 degrees or 80 degree position. Variability within each group was very high which increases the chance of not detecting a difference when in fact one may truly exist.

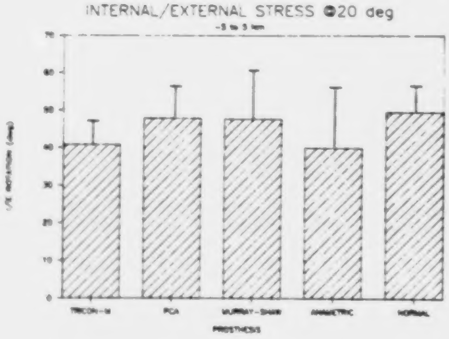

Table 4.

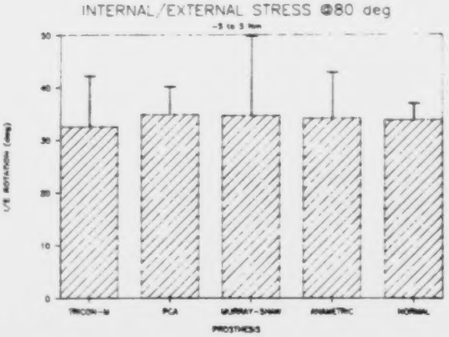

Table 5.

The screwhome data was inconclusive due to variations in the patients range of motion. This was due to lack of full extension post-op and inability of older patients to get full extension while in the Genucom. These problems prevented a suitable reference position to be established to measure the resulting internal/external rotation. Muscular control and resistance in the terminal degrees of extensions also account for high interpatient variability.

DISCUSSION

Total knee arthroplasty has been a significant improvement in the treatment of gonarthrosis. There has been a proliferation of prostheses designed to duplicate normal knee function. The literature is abundant with clinical series showing the adequacy of many specific total knee designs. Our present study quantifies the differences between four prosthetic designs in the *in vivo* situation.

Significant differences from normal were seen only in the Anametric and Variable Axis protheses. These two prostheses were more lax in varus/valgus testing. There is no obvious design feature which would account for this. Because this is a consistent finding, it is difficult to attribute this laxity to surgical technique.

The Variable Axis total knee prothesis seeks to provide a substitute for the cruciate ligaments (3). It has a central ball and socket articulating configuration. This design was significantly more stable than the normal knee in the anterior/posterior testing.

Future studies could correlate measured displacement and radiographic alignment of components, or variations in operative technique. This may better delineate these variables and the roles they play in the functional result of knee replacements.

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DATA COLLECTION ON GAIT AND ENERGY EXPENDITURE OF ABOVE KNEE AMPUTEES

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ABSTRACT

This paper reviews past and present gait analysis techiques. Next equipment at the Oklahoma City Veterans Administration Medical Center Motion Analysis Laboratory is discussed. Last an ongoing pilot study of unilateral above knee amputees is detailed.

INTRODUCTION

Objective analysis of gait characteristics has been a long time goal of researchers. Coupled with monitoring of heartrate, oxygen consumption, and muscle activity, data on gait parameters gives researchers tools to study normal and abnormal locomotion. Study of amputee gait was one of the earliest applications of motion analysis labs.

In the past, gait has been studied in a number of ways. Electrogoniometers, foot switches, switches imbedded in walkway mats, and ultrasonic sensors are among the techniques employed to measure gait parameters such as toe and heel contact, stride length and time. Hannah and Cooper (1) used electrogoniometers to measure hip and knee angles during walking. Bontrager et. al. (2) used foot swiches to record foot to floor contact at four points on each foot. Taylor (3) developed a four meter walkway with 512 pressure switches. A microprocessor stored the time each time a subject's foot activated or released a switch. Pinzur et. al. (4) developed an ultrasonic limb position monitor for attachment to a subject's ankles. Using this apparatus in conjunction with elecromyographic equipment, the researchers were able to produce a multichannel strip chart of the subject's gait pattern.

Some researchers have placed markers on body joints for study, filmed the joints in motion, and then manually entered the marker coordinates into a computer on a frame by frame basis. This transfer from motion picture is a time consuming and tedious process. From this data the computer could then reconstruct the joint motion for futher analysis.

As computers and programs have advanced, real time data capture has been made possible. Such systems as the Vicon Motion Analysis System have eliminated the manual data entry step, allowing researchers more time to analyze and present gait data.

Hannah and Cooper stated "Interpretation of gait data is at least as large a problem as obtaining it in the clinic. Gait is complex, many variables are present, and clinicians are often not receptive to a complex presentation of the results of a gait analysis."

Newer computers and programs have allowed more sophisticated analysis and display of gait data, helping to make research and clinical inferences easier.

The Oklahoma City Veterans Administration has acquired a Vicon Motion Analysis system, the first in a VA facility. The Vicon system uses four cameras with infrared strobes to detect markers placed on body segments under study. With some researcher intervention, the system can determine the markers' paths. From this data, stick figure representations can be produced. The system can simulate the viewing perspective from any angle, and can monitor ten channels of EMG. Oxygen consumption and energy expenditure can be determined using a CAD/NET 2001 made by Medical Graphics.

Figure 1 shows the OKC VA Motion Analysis Laboratory. In the foreground are six of the ten channels of EMG, a camera is on the far right, a video monitor on a stand is in the center, and four calibration stands hold five markers each for temporary use during calibration. The towels hanging from the ceiling are used to block direct light to the cameras.

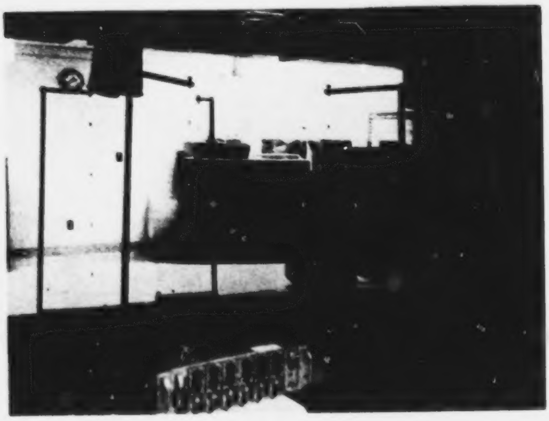

Figure 1, OKC VA motion Analysis Laboratory.

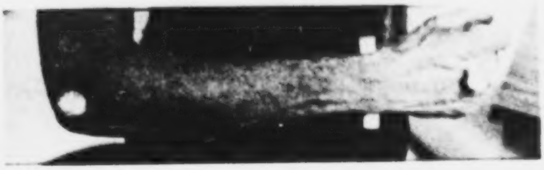

Figure 2 shows a closeup of the markers.

PROSTHETIC SOCKET BACKGROUND

Prosthetic sockets are continually changing as rehabilitation practitioners learn more about the body and technology. The quadrilateral socket was developed in 1954 and has been the standard for above knee amputees. Since its development, some non-quadrilateral sockets have been designed and used. Sockets in this category, compress the residual limb medio-laterally (M-L), rather than antero-posteriorly (A-P), achieving more physiologic hip adduction. Sometimes this is known as a Contoured Adducted Trocanteric Controlled Alignment Method (CAT-CAM) socket.

Above-knee fitting techniques have certainly improved, but the "perfect" socket has yet to be developed. More data on gait analysis and energy expenditure of prosthetic ambulation as it relates to the use of available sockets and components in above knee amputees is needed. This data, if available on the newer prosthetic developments, would allow objective and cost-effective decisions to be made in an area that has been largely subjective.

CURRENT RESEARCH

At the OKC VAMC, a pilot study is in progress, to generate a data base on twelve unilateral above knee amputees. In order to limit the number of variables, participants in the study must be male, have a femur length equal to or greater than 4", and have no history of cardiovascular disease. The gait and energy expenditure data will be collected on the subject using first the quad socket and then the non-quadrilateral. Data collection on the subjects' non-quadrilateral socket use will be repeated in three months. To date, data on two subjects has been collected. Graphics of one of these subjects is presented as figures 3-5.

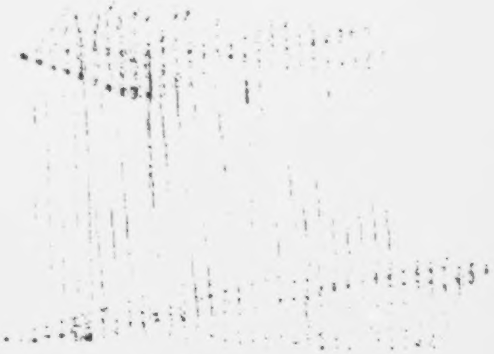

Figure 3

Figure 3 shows an overhead view of a stick figure reconstruction of a right above knee amputee for 14 consecutive images taken 20 milliseconds apart.

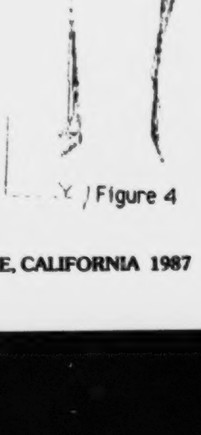

Figure 4

Figure 4 shows every third frame of 14 images taken from a front view.

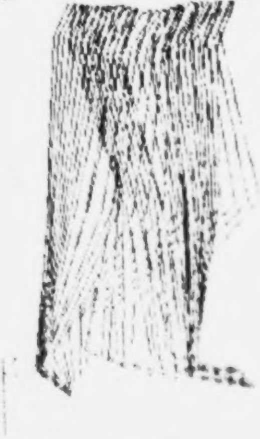

Figure 5

Figure 5 shows 14 consecutive frames of a right side view.

While data analysis has not been completed, there may be differences between gait patterns of the two socket types. There may also be a difference in energy expenditure but the number of completed subjects does not allow statistical signifigance at this time.

AKNOWLEDGEMENT

This research is made possible by a pilot grant from the Veterans Administration Rehabilitation Research and Development Service

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CONCLUSION

Recent developments in computer processed imaging systems will allow researchers to objectively study gait characteristics in an easier and more detailed manner.

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QUANTITATIVE FUNCTIONAL ASSESSMENT OF CONTROL SYSTEMS FOR UPPER-EXTREMITY PROSTHESES

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ABSTRACT

A practical technique for the design and evaluation of elbow prostheses has been developed for use in a laboratory environment where resources and manpower are limited. Prospective designs are emulated with a combination of hardware and software as opposed to constructing actual prototypes. Design changes may be examined simply by reprogramming the dynamic behavior of the emulator rather than by reconstructing hardware. The system can emulate existing powered elbow prostheses and, to a limited degree, some important characteristics of the intact elbow. Evaluation of prosthesis designs is based on the ability of amputee subjects to perform tasks of daily living while operating the emulator. An experiment was performed in which amputee subjects executed a simple constrained motion task with the emulator. Two prosthesis designs were simulated and compared in a side-by-side manner; these were a conventional myoelectric prosthesis and a prospective prosthesis with control similar to the natural elbow. The result was that the natural controller facilitated constraint accomodation.

INTRODUCTION

Bringing an assistive device to a marketable state can be difficult given the many factors that must be considered. Complex physiological details of the human body, engineering and economic issues, and human factors such as comfort and ease of operation are each important. It is not unlikely that several prototypes may be required before arriving upon an acceptable design. Moreover, testing with prospective users and evaluation from various professionals in pertinent fields should be included at intermediate stages.

Often industrial participation is not available during the middle stages of product development since the complexity of the problem is counfounded by a limited market size and a high risk of marketing failure [1]. As a consequence much rehabilitation research is performed in research laboratories such as those found in academic institutions. Once clinical and economic feasibility are established to the point where participation is attractive to industry, the transfer of technology from the research laboratory to the commercial manufacturer can be made.

This paper presents a *practical* technique to aid design and evaluation of a particular class of assistive devides. The technique is applied in an academic research laboratory to improve artificial elbows for above-elbow amputees. Prospective designs are emulated with a combination of software and hardware as opposed to attempting construction of field-wearable prototypes. In this manner no further hardware is required once the emulator system is completed; design changes are examined simply by reprogramming the dynamic behavior of the emulator. Design evaluation is based on the ability of amputee subjects to perform tasks of daily living while operating the emulator. The final product of the research will be specifications usable by a facility equipped to fabricate production versions.

BACKGROUND

Elbow-prosthesis emulation

The emulator system, Figure 1, consists of a high-performance electrically powered elbow prosthesis worn by an amputee and interfaced to a digital computer [2]. Change of the inherent prosthesis dynamics to desired dynamics is achieved with a digitally supervised analog control circuit. Power and control are externally supplied to the elbow via an "umbilical" cord allowing greater performance for given size and weight constraints on the device. The amputee commands the machine with myoelectric activity (MEA) measured from the remaining musculature in his stump and/or shoulder girdle.

Why not use a purely software simulation? Although this technique would require no hardware other than the digital computer, its implementaion would pose several fundamental difficulties. First of all, modelling the human operator and his environment would be highly impractical. Secondly, obtaining assessment from the amputee and from other professionals would be difficult for the experimenter. Finally, an evaluation of the amputee's safety would be restricted and unconvincing.

In contrast the emulator system is well suited to the artificial-elbow design problem. Combining the computerized facility with the human operator allows direct acquisition of quantified technical data from the prosthesis in addition to less technical information from the amputee user. More important, a broad range of prosthesis characteristics can be tested experimentally with a minimum of uncontrolled variables; modifying a single feature of a prospective design while keeping other variables constant allows the effect of that feature to be distinguished. For example, either an electric or a pneumatic motor can be simulated with appropriate programming of the emulator dynamics, and yet the prosthesis harnessing, weight and inertia do not vary. Furthermore, since the arm need not be removed from the amputee, the positioning of the myoelectric-activity sensing electrodes does not vary either. Alternatively, the actuator type can be fixed while the prosthesis controller is altered; that is, the manner in which the amputee commands the elbow with MEA may be changed. Many other combinations of features can be investigated.

Examining a broad range of characteristics is essential to developing a replacement for the natural limb. The intact limb is very complex, and much of its function is still not understood. Hence the requirements upon the prosthesis are not clearly defined, and the designer must include what he feels would benefit the amputee and then test it. A further difficulty arises from the limits of state-of-the-art technology and medicine. Even that which is understood about the intact limb could not be replicated in a prosthesis. Experimentation is required to determine what is possible and what is useful to the amputee.

Additional benefits are offered by the emulator's high performance. Since it outperforms conventional devices, the emulator allows more distinction between the amputee's capability and the limits imposed by the hardware. Also, observation of some designs is possible before they can be practically realized given the state of the art in manufacturing and the requirements on the prosthesis.

Design considerations for the emulator

Since the goal is to improve artificial elbows, the emulator, at the least, must perform as well as existing devices. Characterizing the performance of present prostheses is relatively straightforward. Typically the load-lifting capability (torque) and peak rate of flexion (angular speed) are specified. In reference [2], which contains a detailed description of the emulator design, it is shown that the emulator does bracket the torque and speed of two prominent state-of-the-art artificial elbows: the Boston Elbow and the Utah Arm.

Ultimately, a prosthesis will restore the functional capability of the intact limb, and therefore the intact elbow serves as an upper limit on performance for the emulator. Why attempt to mimic the performance of the intact limb? Although a complete characterization of the human arm has yet to be performed, recent neurophysiological research has yielded a greater understanding of the importance of the dynamic behavior of the limb for motor control [3,4]. If the emulator could mimic this behavior, then it could be used to address such questions as the following: 1) if a prosthesis had dynamic behavior comparable to the natural limb's, could an amputee control it via bioelectric signals? 2) would such a device give an amputee capability more like that of the intact limb?

In addition to generating the forces that cause movement, skeletal muscles behave as tunable springs and dampers; muscle force depends not only on the level of neural activation, but also on the muscle length and rate of change of length [4]. This length and rate dependence gives the muscle an effective stiffness and viscosity, that is, mechanical impedance. Increasing the neural activation increases both the force and the impedance of the muscle. With antagonist muscles coupled about a joint, the forces (and hence the torques) subtract, whereas, the impedances sum. Consequently, differentially activating the antagonist muscles produces a net driving torque about the joint while coactivating increases the net joint impedance.

Intact humans can voluntarily modulate the mechanical impedance of the neuromuscular system, and Hogan has postulated that this ability facilitates many important skills: postural stabilization, trajectory control, constraint accomodation and tool use [4,5]. The question remains as to whether or not a prosthesis with controllable mechanical impedance would improve an amputee's functional capability. It has been postulated that the prosthesis would respond "naturally" to movement commands in the form of MEA from the amputee by utilizing these natural patterns of muscle coordination [2,6]. To test this concept, the emulator was designed to achieve the range of impedance observed with the intact elbow.

Approximate bounds on the stiffness and damping of the intact human elbow joint are discussed in reference [2] and summarized below. Note that the dimensionless damping ratio is specified rather than the damping factor. However, the latter can easily be computed from the former given the stiffness and the inertia, which for the emulator is 0.060 kg-m^2. The emulator can achieve this range of impedance, although it inevitably falls short of the intact elbow's peak torque and speed [2].

	Stiffness K_0 (N-m/rad)	*Damping Ratio* ζ
minimum	1	0.1
maximum	200	1.0

METHODS

Specification of desired prosthesis dynamics is achieved under program control with the controller circuit [2]. The digital computer periodically samples the amputee's MEA and the current state of the prosthesis, and subsequently computes and downloads parameters to the circuit. These parameters are the gains of and reference inputs to analog feedback loops that have been closed about the elbow actuator. Position, velocity and torque feedback are used. The torque-feedback loop conditions the inherent prosthesis dynamics reducing nonideal effects, while the position and velocity loops give the effective stiffness and damping, respectively.

Two examples of prosthesis simulation are presented here: the emulator was programmed to behave as the Boston Elbow [7] and, to a limited degree, as the natural elbow. A side-by-side comparison between the two prosthesis control schemes was then made by having the amputee perform a task representative of many daily activities: turning a crank. Several important skills were required: 1) accomodation of a nontrivial constraint, 2) postural stabilization against gravity, and 3) multiple-joint coordination. Quantitative evaluation of performance was made with records of data taken from the elbow's torque, angle and angular-velocity transducers. Also, qualitative assessment was obtained from the amputee subject.

The Boston Elbow implements a velocity controller; that is, the difference in magnitude of the amputee's biceps and triceps myoelectric signals is used to command the angular velocity about the elbow. When the amputee relaxes, the motor stops, and a reverse-locking clutch prevents the elbow from being driven by external torques. Programming the emulator to mimic this scheme is straightforward. The processed biceps and triceps signals are read into the computer with analog-to-digital converters. The difference is taken and used to compute the reference input to the velocity-feedback loop. To simulate the reverse-locking clutch, the emulator implements a high-gain, position-feedback loop.

With the natural control scheme, the amputee not only can command a driving torque at the elbow but also can modulate the mechanical impedance about the elbow by synergistic coactivation of antagonist muscles. The emulator specifies the stiffness by making the position-feedback gain a weigted sum of the biceps and triceps MEA. The velocity feedback gain is adjusted to maintain a constant damping ratio to keep the prosthesis well behaved. A driving torque is generated via specification of a "virtual" angle [4] for the elbow. The actual angle of the elbow, θ, tends toward the virtual angle, θ_{vir} during movement and coicides with it at equilibrium except in the presence of external loads, τ_{ext}, on the forearm. In this manner, the prosthesis obeys the following equation of motion:

$$I\ddot{\theta} + B\dot{\theta} = K(\theta_{vir} - \theta) + \tau_{ext}$$

where I is the forearm inertia, B is the elbow damping and K is the elbow stiffness. The virtual angle is specified with the reference position input to the circuit.

Three adult male unilateral amputees wore and operated the emulator prosthesis in order ro turn a simple crank that was fixed to rotate in a vertical plane. The crank was crudely constructed from aluminum with steel bolts used for shafts at the pivots. Although no load was added to the crank, there was significant friction due to the bolts.

RESULTS

Figure 2 represents a typical trial of an amputee turning the crank. The output of the torque transducer is plotted against the angle of the crank axis. Zero degrees is the upward vertical position, and positive rotation occurs when the subject brings the crank downward toward himself. A positive elbow torque represents flexion. The figure shows lifting of the crank in the negative direction from the 180 degree position with the emulator: 1) mimicing the Boston Elbow (velocity controlled prosthesis) and 2) operating with natural or impedance control.

The key difference between the two trials is in the transition from flexion to extension, which for the impedance controller occurs over about twice the angle change observed with the velocity controller. Motion with impedance control appeared to be more fluid, and according to the subjects was much easier to perform. In an amputee's own words, he experienced a "time delay" while operating the velocity controller. Elaborating, he stated that he had to pause and decide when to change from flexion to extension. Otherwise, if he did not time the movement properly, he would drive the crank back down rather than upward when extending the elbow.

CONCLUSIONS

Controlling the *motion* of the elbow with the velocity controller places a mental burden on the operator since both the prosthesis and the crank are attempting to simultaneously specify the trajectory. However, the impedance controller allows the elbow to comply with the constraint while providing a driving force with a component tangent to the crank's path.

ACKNOWLEDGEMENTS

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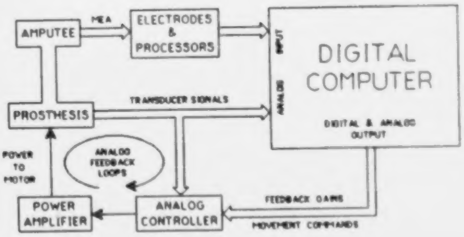

Figure 1: Schematic of the elbow-prosthesis emulator system.

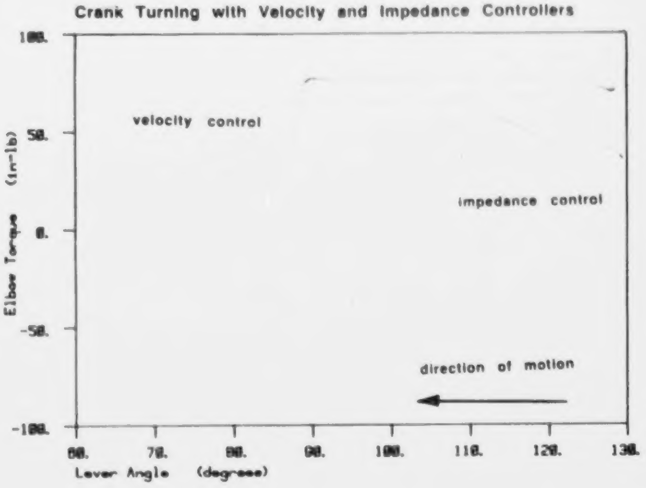

Figure 2: Amputee subject turning a crank while operating the emulator.

A NEW TOOL FOR STROKE REHABILITATION STUDY

Satoru Isaka, * Alan M. Schneider, Sc.D., *
Philip Filia, *** Kok Keun Lue, *
Richard D. Coutts, M.D., ** Vernon L. Nickel, M.D. **

ABSTRACT

This paper describes a new measuring system that is currently being used for stroke patient rehabilitation study at Sharp Hospital in San Diego, CA. The system consists of an orthosis with sensors, an interface box, and a data processor with peripherals. Precise measurements of the motion at the knee joint of a stroke patient are obtained by the sensors, and are fed into the processor which provides a reliable, repeatable, quantitative measure of the patient performance. The results can be displayed in graphs and tables using an interactive book-keeping program called "SPRP".

I. INTRODUCTION

There are 400,000 new stroke victims yearly in the United States. Over 2 million people have survived from the stroke, and their mean survival period is more than 7 years. Rehabilitation of those stroke survivers is, therefore, urgently needed; however, because of limited man-power and cost, sufficient resources for rehabilitation are not available at this point. Furthermore, there is not yet a single rehabilitation method that is proved to be effective for stroke patients.

At the University of California, San Diego (UCSD), Coutts and Nickel et al have been evaluating the effect of motion on the rehabilitation of patients recovering from a stroke. Because of the damage to the brain from the stroke, these patients suffer varing degrees of paralysis of one of the lower extremities. The paralysis improves over time, depending upon the amount of healing that takes place in the injured brain tissue. The hypothesis being tested by these investigators is that the healing process can be influenced positively by repetitive patterning of the paralyzed limb (a process referred to as neuroplasticity). The patterning of the limb is produced by a motorized orthotic device known as a continuous passive motion (CPM) machine. Patients have received treatment in this machine once per day for an average of 2 hours.

A major requirement of this study was the need for a method to measure quantitatively the effect of this treatment. To this end, an orthotic device identical to that used to treat the patients was instrumented to provide angular position, velocity, acceleration, power and energy of a voluntary active movement of a limb strapped into the orthosis, as well as isometric strength of the quadriceps and hamstring muscles. This report describes the development and validation of this measuring device, developed jointly by UCSD and a local technology firm, Sutter Biomedical Inc., in San Diego. Fig.1 shows the CPM device (Sutter 9000) and the orthosis.

II. THE MEASURING SYSTEM

The rehabilitation process measuring system is composed of essentially three parts [Fig.2] -- an orthosis, an interface box, and a data processor with peripherals. The orthosis, whose outer frame is a modification of Sutter 9000, has three sensors to take measurements from stroke patients' lower extremities-- a shaft angle encoder, an accelerometer, and a force transducer. The signals from those sensors are fed into the data processor IBM PC/XT through the interface box. The data processor computes various parameters from these signals and stores them in appropriate output files. The results can be printed or viewed on the monitor screen using a special book-keeping program called "SPRP", explained later.

The measurements are divided into two parts: repetition of flex/extend motion of knee joints and static force measurements. Lying horizontally, the patient

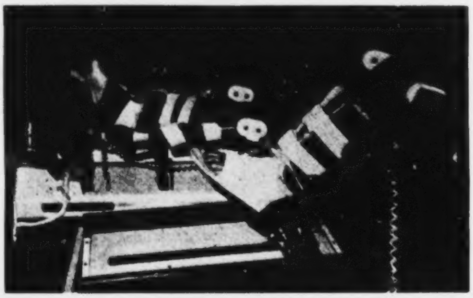

Fig.1 The orthosis (the measuring device, the foreground) and the CPM device (Sutter 9000).

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*** Sutter Biomedical Inc.

flexes and extends his knee. The shaft angle encoder measures the knee joint angle at the sampling rate of 50 Hz (50 samples per second). Currently, in our experiments, we are asking patients to repeat flex/extend motion as many times and as hard as possible for 10 seconds. Hence, a single test will produce 500 data points. These data, representing knee joint angles with respect to time, are then digitally processed to derive angular velocity, angular acceleration, energy, and power versus time, from which the following summary data is extracted:

1. maximum range of motion
2. maximum angular velocity
3. maximum angular acceleration
4. maximum energy dissipated by the patient
5. maximum power.

Using the force transducer, static force measurements are obtained independently of the previous motion, providing:

6. maximum knee flex force
7. maximum knee extention force.

These data are saved in each patient's output file, and used as a quantitative measure of the patient's progress. The significance of some of the parameters is obvious (e.g. #1, 6, and 7). The more important feature of this system, however, is the capability of producing a measure of a patient's strength, not only from the static force measurements but also from the continuous motion of lower extremities. The computation of the measures such as energy and power requires knowledge of a patient's physical size, such as circumference of thighs and legs. Selecting a few key indices for the evaluation of the rehabilitation process, using all the information available, is a primary goal for this research.

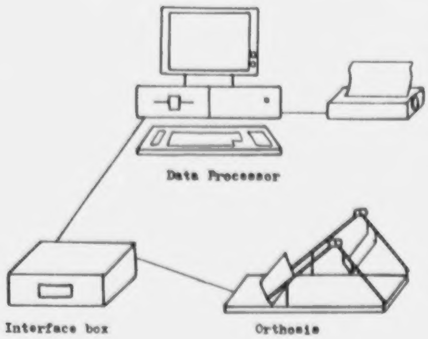

Fig.2 System apparatus for stroke patients testing.

III. THE BOOK-KEEPING PROGRAM

Now, let us take a look at the system software that manages all of the extra things that people otherwise have to do by themselves, such as keeping track of patients' records, drawing line graphs of test results, summarizing results in a table, etc. We have developed an interactive book-keeping program called "SPRP" (Stroke Patient Rehabilitation Program) to meet our specific needs. The following is the main menu of the SPRP:

MAIN MENU
1 - Check Inventory
2 - Patient Information
3 - Tests
4 - Data Process
5 - Graphs
6 - Table of Test Results
ESC Key - Exit

This tells us what this program can do, as summarized below by menu number.

1. It can show what files are currently in the directory.
2. It can create, modify, or review a patient's general information files, which contain information such as name, age, date of stroke, side of brain affected by stroke, etc. The files also contain each patient's body size -- height, weight, leg length, etc. --used for computing energy and power during the tests.
3. It gives directions to the operator for performing the test. It keeps track of the patient's name and ID code, experiment number, and the side of the leg being tested, so that the operator simply follows the directions given by the program.
4. Because of the complexity of the algorithm for computing energy and power, it takes a few minutes to process all 500 points of data. Therefore, after each test, only the raw data are stored to save time for both the patient and the operator. Tests can be performed consecutively without processing each time. Meanwhile, the program keep track of the number of tests performed and which tests are to be processed, so that the operator can process the test results later on, without remembering which tests should be processed. After the processing, the results are stored in appropriate output files.
5. It has a graphic capability. It can draw line graphs of test results (e.g. knee joint angle vs. time). Graphic presentation of test results is an important and effective tool for the analysis.
6. It can summarize all the test results for each patient and display them in a table. This table is useful in that patient changes over time can be detected at a glance.

IV. SAMPLE RESULTS

Here we present some of the results from actual tests. Figs.3 and 4 are the time series graph of knee joint angle and power, respectively. The consistent motion of knee flex/extend shows that this patient has normal function of his/her lower extremity. The table below is a summary of test results. It contains test numbers, dates, and seven parameters explained in Sec.II. If any improvement of a patient's performance occurs over time, these parameters should indicate such change quantitatively (e.g. range of motion increased 10% after a month of CPM treatment). Furthermore, these parameters can be used not only for an individual performance anaysis, but also for a statistical analysis of a number of patients who are grouped by certain criteria.

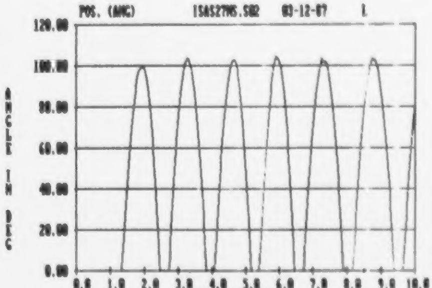

__Fig.3__ The knee joint angle vs. time.

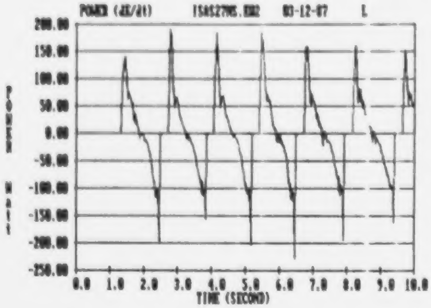

__Fig.4__ Power vs. time.

V. CONCLUSIONS

This paper describes a new measuring system that is currently being used for rehabilitation study. As of 3/10/87, about thirty stroke patients have been tested on this system, and interesting results are becoming to come out. As mentioned in the introduction, rehabilitation research is in urgent demand more than ever in the age of high-technology. Although this system is a forward step in the field, it is still a prototype, and there are possibilities for improvement. It is the authors' intention that the introduction of this measuring system to the various personnel in the related fields will give valuable feedback to the project, and open up a new dimension in rehabilitation research.

VI. ACKNOWLEDGEMENTS

We would like to thank Dr. Field Blevins of Sharp Hospital for his valuable contributions to the project. Partial support of engineering analysis by the Garrett Corporation is gratefully acknowledged.

VII. REFERENCE

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Experiment results for ISAS27MS [LEFT leg]

EXP#	DATE	Max.Pos (deg)	Max.Vel (deg/s)	Max.Acc (d/s**2)	Max.Ext (N)	Max.Flx (N)	Max.Egy (Joule)	Max.Pwr (Watt)
1	03-12-87	103.3	289.6	4100.9	42.1	30.1	33.8	145.2
2	03-12-87	103.8	365.3	5608.8	38.8	25.5	34.4	228.4
3	03-13-87	103.1	345.2	4603.7	41.2	26.2	33.9	167.6
4	03-14-87	103.9	370.1	5679.9	43.1	30.3	35.2	245.9
5	03-14-87	103.4	364.3	5622.1	42.2	30.2	34.9	243.2
6	03-14-87	103.8	366.3	5701.8	43.0	30.5	34.2	244.4

__Table__ Summary of test results of six experiments on one patient.

TECHNOLOGY FOR CLINICIANS: MEASUREMENT OF FUNCTIONAL COMMUNICATION OF PERSONS WITH APHASIA

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ABSTRACT

Developing functional communication is the goal of Speech-Language rehabilitation treatment of persons with aphasia. The Communication Analysis System (CAS) uses electronic and behavioral technologies to help Speech-Language Pathologists (SLPs) in this effort. Inexpensive personal computer technology (an Apple with a numeric keypad and a clock) is the hardware for the system. The CAS uses an advanced behavioral measurement technology to provide convenient, objective, ratio-quality quantitative measures of client and clinician behaviors. Data displays designed for fast interpretation allow the clinician to analyze rapidly the extent to which the treatment was implemented as planned and its effects on client communicative behavior. Cost-effective treatments can thus be maximized.

INTRODUCTION

In Speech-Language rehabilitation of persons with aphasia, the fundamental goal of treatment is to improve the patient's functional communication (e.g., communication during conversational speech.) Speech-Language Pathologists modulate their own communicative behavior in specific ways to pursue this goal.

Decisions about implementing and continuing treatment procedures should be supported by objective data on patient outcomes. A number of systems to assess patient-clinician interaction are currently available (Bales, 1970; Boone & Prescott, 1970; Brookshire, 1978). However, these systems are typically too cumbersome or time-consuming for widespread, routine use in the clinical situation. As a result, subjective ratings of progress are frequently used to support clinical decisions.

This paper describes a system of technological tools currently under development which permits Speech-Language Pathologists to maximize cost-effective progress in treatment of persons with aphasia.

BACKGROUND

In clinical settings it is difficult for one person to collect accurate data concerning treatment effectiveness while at the same time delivering such treatment. Since treatment procedures involve the clinician's behavior, assessment of treatment effectiveness depends on the extent to which the planned treatment was actually applied. SLPs must also consider factors outside their control which may affect patient performance.

To maximize cost-effective treatment, SLPs need data on their application of clinical procedures as well as on patients' functional communication. Ideally, the system should provide objective, ratio-quality, continous data. Data collection should be inexpensive, unobtrusive, and frequent. Finally, data analysis must be rapid and meaningful.

With the CAS, the SLP tracks 22 classes of communicative behavior events. During a conversation, the clinician depresses the appropriate key when a classified event is completed. Data collection routines code the event, and keep the exact time of day of each occurrence. File management routines keep each session's data on disk and coordinate data analysis.

METHODS

Apparatus.

Data collection using the CAS system requires a personal computer of the Apple II family (II, II+, IIe, IIc) equipped with one disk drive, some clock capability, an ABT, Inc. numeric keypad, and at least 64K RAM. A IIc, II+, or IIe must be equipped with either a commercial clock card or a mousecard. For the IIc or Apple with a mousecard, a 'jiffy clock' is implemented in software that takes advantage of the 60 Hz interrupt available from the mouse firmware (Merbitz, Grip and Marqui, in press).

The ABT, Inc. numeric keypad (see Figure 1) was chosen because of its convenient size and shape when held sideways. It is connected to the Apple by a 2 meter cable terminating in a D-9 connector. A short jumper (supplied) plugs into the IIe motherboard. It also comes with an adapter designed to be soldered to the keyboard encoder board of the II and II+. For use with the IIc, we have inserted a T-connector into the ribbon cable connecting the keyboard and the motherboard. A short ribbon cable is soldered to the appropriate leads of the T, and from there leads out of the IIc enclosure and is terminated in a D-9 for the keypad.

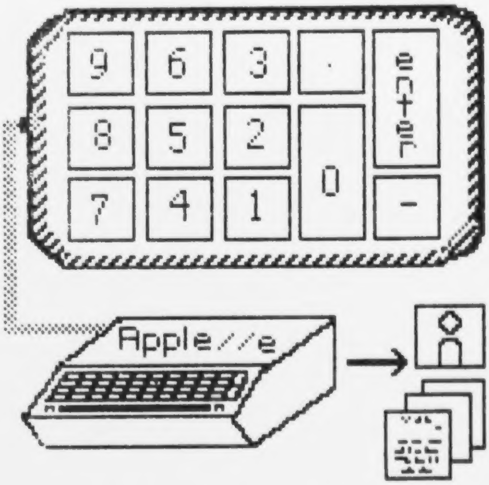

Fig. 1. Diagram of the elements of the CAS hardware. The keypad is usually held in the orientation shown. Event codes corresponding to the key map are given in Table 1.

Communicative Behavior Codes.
The system is designed to record the occurrence of 22 classes of important communicative behaviors. Definitions of the patient and clinician communicative behaviors are listed below. Each set of codes is mapped on the numeric keypad. The clinician selects the active set with one keystroke (- for patient, 7 for clinician) and subsequent keystrokes record the trailing edge of coded events in that set until the other set is selected. To minimize the effort required to learn and use the system, the keys which record many classes of behavior (such as questions) are the same.

Table 1. Keys, code abbreviations, and definitions of the codes. The abbreviations appear on a screen display of the keypad during data collection, with the most recently depressed key highlighted. Refer to Fig. 1 for the physical location of the keys.

Key	Abbreviation	Definition
		Patient Codes:
-	PT	Patient is communicator; all subsequent keystrokes record patient events until 7 is keyed.
RET	PQUES	Pt. asks question or gives directive.
0	PANSR	Pt. answers correctly; gives short, appropriate response. (Ex.: yes/no)
.	PSAYS	Pt. gives correct statement or elaboration.
1	PGES	Pt. gestures appropriately, in context.
2	PAGIN	Pt. reiterates or repeats utterance
3	BITOF	Pt. utterance generally correct, not perfect. Clinician does not need to interpret.
4	PWRIT	Pt. writes correct communication
5	NR	Pt. does not respond
6	INTRP	Pt. utterance understandable with unacceptable work by listener; Clinician can and must interpret utterance for communication; some words unintelligible/substituted.
7	TX	Clinician speaks: other set of codes becomes active.
9	FAROF	Pt. utterance not understandable even w/ interpretation; silent, unsuccessful attempt; or wrong, false, incorrect, (as when following a question), or garbled, unintelligible.
		Clinician Codes:
-	PT	Patient speaks; other set of codes becomes active.
RET	TQUES	Clinician asks question or gives directive.
0	TANSR	Clinician answers question or request.
.	TSAYS	Clinician makes statement
1	TCUE	Clinician presents cue
2	TAGIN	Clinician repeats previous utterance.
3	T++FB	Clinician gives positive feedback to pt.
4	TWRIT	Clinician writes
5	PROC	Clinician initiates new procedure; next keystroke is Procedure ID #.
6	T-+FB	Clinician gives mixed feedback
7	TX	Clinician is communicator until - is keyed.
8	FLAG	An unclassified event or marker, as for an error in coding.
9	T--FB	Clinician gives negative feedback

Procedure.
During treatment the aphasic patient's and therapist's communications are coded by the therapist. Each time the therapist depresses a key on the keypad the event's code and time of its occurrence are stored in the computer. The CAS data collection software simply writes the time of day of each keystroke and saves the ASCII value of the keystroke. It also displays a map of the keypad codes on the screen, with the most recently used key highlighted. When a treatment strategy is changed within the session the point of change is marked by the therapist using the Procedure key. During data analysis the file of the session can be split at the point of change in the treatment and the parts of the session can be compared. If one treatment strategy is superior to the other, it will by definition result in a change in patient communications.

At the end of the session, a separate file management module saves the resulting sequential time- and date-stamped file on a floppy disk for later analysis. The sessions may also be videotaped, so that off-line coding of the session can measure accuracy. Finally, the data analysis component reads the files and provides screen displays or hard copies of the files and analyses.

Reliability.
To establish reliability and accuracy of the clinician as an observer, treatment sessions are scored by a second clinician either simultaneously or from video tape. The video tape may also be scored by the original therapist for checking intraobserver reliability. The reliability check component of the CAS system reports the agreement between observers.

Data Analysis.
CAS data are examined using a system under development at RIC for analysis of a variety of behavioral data. Within-session data analysis commands provide details of the flow of events. These include displays of the clinician's accuracy as an observer, lists of events, frequencies, and sequences, and graphics of the flow of events in the session. These analysis tools facilitate the search for relationships between the clinician's procedures and the client's performance. Figures 2 and 3 show event records of sessions during which the clinician applied several procedures.

Between-session data analysis commands include a plot of behavior frequencies (count per minute) per day, so that level, variability, and direction and rate of change of behavior over the course of treatment can be seen.

DISCUSSION

With the CAS, the Speech-Language Pathologist has a powerful set of tools to help the clinician maximize cost-effective treatment for persons with aphasia. Frequent, inexpensive, objective, ratio-quality measures of a range of the patient's communicative behavior are available, with simultaneous measures of the behavior of the clinician. The provision for measuring both routinely allows the clinician to see the effects of treatment changes on patient progress. The measurement of multiple behaviors also allows the possibility that changes due to events beyond the clinician's control can be seen. The CAS allows the therapist to try different interventions and immediately analyze the results. Changes in the type and frequency of a patient's behavior can be related to various treatment interventions. With this type of experimental approach, greater assurance that progress is due to the application of specific treatments can be reached, and greater, more cost-effective progress for patients will result.

ACKNOWLEDGEMENTS

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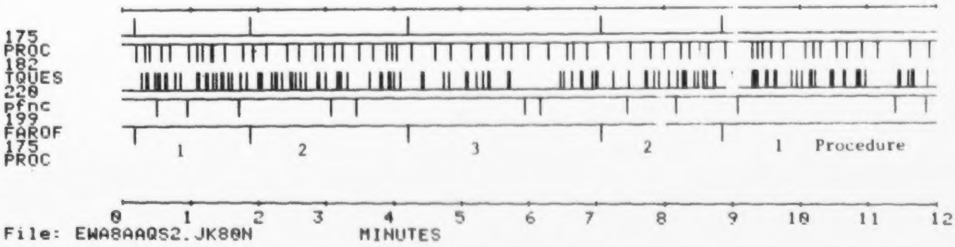

Fig. 2. Event records of one functional communication session. Procedure number 1 indicates use of the standard procedures for conversation with aphasics during speech treatment. In the Procedure 2 phase, the clinician used yes/no questions, while Procedure 3 employed open ended questions. Procedure numbers are indicated at the bottom, above the time line. Classes of behaviors are labelled on the left. The "PFNC" class is an aggregate of all functional communication behaviors by the patient, as contrasted to the "FAROF" (nonfunctional) class. As the patient's oral expressive language skills improve, a goal is a higher frequency of PFNCs while the TQUES frequency remains stable or decreases, across various types of communicative environments.

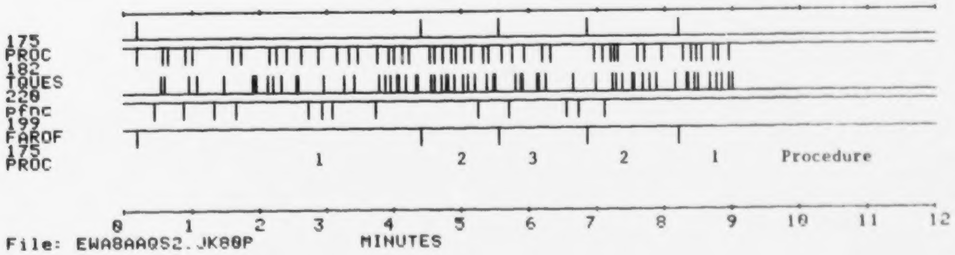

Fig. 3. Event records for a session one week later. Codes are the same as in Fig. 2.

APPLICATION OF A DEVICE FOR THE QUANTITATIVE TESTING OF MUSCLE STRENGTH

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ABSTRACT

The advantages of conducting muscle strength testing with a mechanical device designed for accurate quantification are evaluated. The need for quantifiable data on muscle strength and the rate of deterioration in muscular disorders is underscored, and the Force Evaluation and Testing (FET) System is examined for this purpose. Its use during a drug-trial study of Duchenne muscular dystrophy indicates its usefulness as a tool to chart the tempo of a disorder and the efficacy of treatment.

INTRODUCTION AND BACKGROUND

The principal manifestation of neuromuscular or musculoskeletal disorders is a loss in muscle strength. In an examination of the development of these disorders, it becomes crucial to observe this decline. It is important, then, to devise accurate and reliable tests to measure the deterioration of strength as well as the effects of any treatment on a disorder.

Systems have been developed which grade the relative functional motor performance of individuals, and these have proved superior to crude clinical estimates of muscle strength (1,2,3). However, functional ability tests can lose their value due to outside environmental or emotional factors, and, additionally, they tend to describe periods of stability alternating with rapid deterioration or recovery rather than a detailed linear progression.

Manual methods of muscle-strength testing have been employed in the attempt to draw a more accurate picture. Following standardized procedures in testing muscles against gravity and manual resistance, examiners have quantified muscle strength with a system of letter or numerical grades (4,5,6). This technique has been criticized because it requires an amount of subjectivity in grading on the part of the examiner; hence, it might not always provide a consistently objective scale between examinations, among patients, or among separate studies.

Mechanical devices have also been employed in muscle-strength testing to obtain more reliably objective quantitative data. The expectation was that these devices would both provide a reliable measure to detail the progression of disorders and chart the tempo of recovery from a treatment. Such a test could therefore provide objective data to determine the efficacy of a treatment. The drawback of most mechanical devices had been that, while accurate, they often required a good deal of experience and carefully controlled conditions, which made them impractical in terms of time and effort to use for muscle-strength testing in many clinical environments (7,8,9,10,11,12 13).

In a drug trial study of Duchenne muscular dystrophy, a mechanical device known as the Force Evaluation and Testing (FET) System, (14) which attempts to overcome past drawbacks, was employed (See Figure 1). (The more standard method of muscle strength testing was concurrently employed for the purpose of comparison with data collected in other trials.) Several features of the FET system held the promise of providing quantifiable data as well as the necessary convenience which made it worthwhile to use as part of the clinical study.

METHODS

Equipment. To determine the efficacy of a drug treatment in affecting the rate of deterioration in Duchenne dystrophy, muscle-strength tests become a vital tool. A mechanical device (the FET System) has been included as part of research into this disorder for the past year and a half. The device consists of three major pieces of equipment. First is the hand-held transducer which contains three strain-gauge elements located on orthogonal planes. These elements react independently as external force is applied to the transducer. The advantage of this system seems to be that the three gauges can account for differences in the direction of force, and the force can be centered on any point over the entire surface of the applicator. They do not require the exacting perpendicular positioning of the transducer relative to the tested body part which is required of some other systems which only register a single signal.

Second, these gauges are monitored by a digital information processor, which converts their responses into digital signals. Many samples from each individual gauge are taken by the processor and the proper signals selected to insure the integrity of the data. The values of the signals are then computed to resolve for the single force acting on the transducer. Subsequently, the information is fed from the processor into the host computer, which displays and stores the data as well as prompting the examiner through the various testing protocols.

Application. The device described above was employed as a test of the regression of muscle strength during a drug-trial test for Duchenne muscular dystrophy. Prior to use, the FET System was first calibrated with a systemic check of nine points on the applicator surface: the center, four equidistant points around the perimeter, and four points midway between the center and perimeter spots. During the course of the study, the System was checked at regular intervals by applying a preestablished amount of force at various points on the applicator to confirm that the system was operating accurately.

Many individuals were tested at one to three month

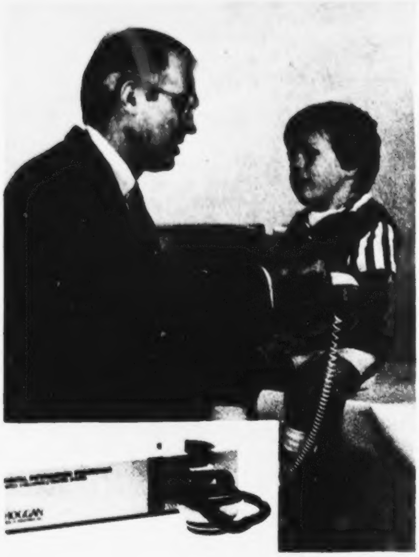

Figure 1. Force Evaluation and Testing System

intervals in the double-blind test. Three attempts with the FET System were made on each of twelve pairs of muscles as part of a slightly modified version of the testing technique described by Daniels and Worthingham (5). The examination used a method of break testing. This muscle strength test examines the amount of force that the examiner must apply to the subject's tensed muscle before the muscle's resistance is overcome. Break-testing using a hand-held dynamometer such as the FET System is well-suited for the study of diseased muscles and also children as in the Duchenne dystrophy study since the examiner is normally larger and stronger than the subject and can overcome the muscle resistance of the subject without difficulty.

The placement of the transducer along a limb was noted in the study and duplicated in each attempt using recognized landmarks on the body in order to keep the factor of the leverage arms constant. The starting position of the involved muscle was duplicated as precisely as possible in each attempt, and a constant, controlled application of force was used to break the resistance of the individual.

RESULTS AND DISCUSSION

At the time of this writing, the data from the Duchenne dystrophy drug-trial is still under double-blind strictures. Disclosures are not available about which individuals received drug treatment and which did not; therefore, no ultimate conclusions can yet be drawn from the data collected by the FET System. However, a preliminary examination of the results from the System indicates that it has produced useful and reliable data for the study. An evaluation of the three testing attempts performed on each muscle demonstrates that in a clinical setting the System consistently produces a repeatable score. (See Figure 2).

As the mean value of a set of three attempts is compared with the mean values from subsequent tests, deteriorating and stable patterns are created, and these patterns appear to follow regular increments of progression. Among the right/left pairs of muscles tested, there is a fairly consistent percentage of progression or stabilization maintained in both memebers of the pair from test to test. (See Figure 3). Further analysis is difficult since it is not yet known what patterns can be attributed to the progress of the disorder, the administration of the drug treatment, or other factors. Yet the use of the device has revealed data (i.e. the changes in the right/left pairs), which the more traditional manual muscle tests might not have the subtlety to record. The possibility of charting precise linear progressions with the data from the tests holds the promise of allowing the calculation of the tempos of disorders and their possible treatments. With this ability and the device's greater accessibility,it is conceivable that more research and study, such as the drug-trial described above, could be conducted in a greater number of clinical environments.

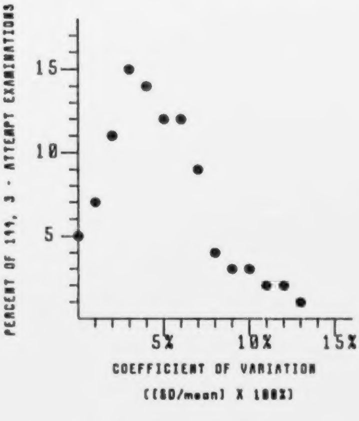

Figure 2. Data for this plot was taken from 3 randomly selected printouts showing each of 3 attempts for 12 pair of muscle tests covering 2 testing sessions. The 3 attempts for each muscle test were compared for a single test session. Attempts used to familiarize the subject with the equipment were not used in the calculations.

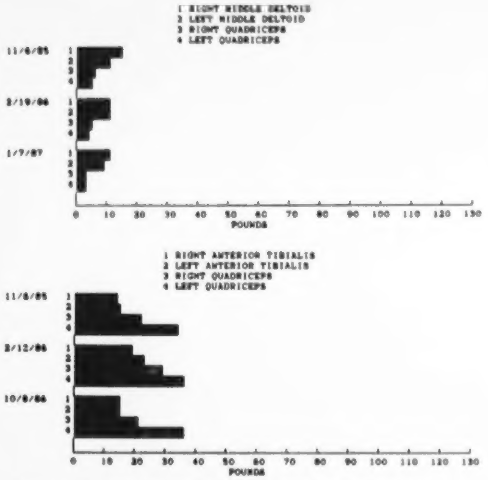

Figure 3. Actual printout from FET System showing typical patterns.

Top graph: Male, 8 years old as of 11/85 weighing an initial 51 pounds, increasing to 57 pounds as of 1/87.

Bottom graph: Female, 12 years old as of 11/85 weighing an initial 70 pounds with no significant weight change as of 10/86.

CONCLUSION

While the Duchenne dystrophy study using the mechanical system of assessing muscle strength has not yet been completed, the device has exhibited its usefulness. Such a device appears to provide a significant step forward to the goal of objectively quantifying muscle strength and its varied progression/deterioration due to neuromuscular and musculoskeletal disorders. It appears especially valuable to the conduct of drug-trials and other clinical studies because it provides convenient, reliable access to the sort of quantifiable data needed to determine the efficacy of various treatments. Eventually, a reliable system of muscle-strength testing could lead to a reliable standard that would allow for a data exchange among researchers and institutions.

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LOW BACK PAIN DISABILITY: COMPARING PHYSICIANS' PREDICTIONS TO EXPERT AND EMPIRICAL MODELS

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ABSTRACT

This study was designed to determine the factors which lead to low back pain disability. A predictive risk model developed by a panel of experts in the fields of chronic pain and disability was tested using data obtained from 92 patients at a low back clinic. Disability as predicted by the model was compared to actual disability assessed 26 weeks later, to predictions of disability made by the attending physicians and to disability predictions obtained from an empirically-derived model. Results of the analysis show that: (a) The expert model performs better than the physicians, although not as well as the empirical model; (b) Although the expert model uses appropriate factors, the weights for these factors are not optimally assigned.

INTRODUCTION

Each year five percent of all American adults experience a low back pain (LBP) episode. Although the majority of those affected recover, some patients have persistent impairments and some become permanently disabled. Currently there are 11.7 million LBP impaired and 5.3 million LBP disabled individuals [1]. The socio-economic impact of this problem is substantial: In 1984 an estimated 7.2 billion dollars was spent in compensation and medical payments for occupationally related LBP disorders and an additional six to eleven billion dollars were attributable to lost productivity. Because other costs were not calculated, the total economic impact may be significantly greater. Simulation models have suggested that the total cost may well be over 20 billion dollars a year [2]. More alarming, the rate of disability from 1977 to 1981 increased at a rate calculated to be fourteen times the rate of population growth [1].

The longer the duration of disabling LBP, the greater the probability of permanent disability. Although 90% of LBP sufferers improve spontaneously within four to eight weeks [3,4] the remaining 10% are likely to remain disabled. Those who are disabled more than six months account for 90% of the cost [5].

Timely intervention during an LBP episode may prevent disability and thus be cost-effective. However, most treatment programs depend upon a generalized rehabilitation strategy applied to all patients [6], rather than customized rehabilitation treatments for different types of patients (for example, those at highest risk). Therefore, a program which could target those patients at high risk for disability would be cost-effective. The objectives of the present study are thus to determine the factors that predict LBP disability so that primary care physicians may correctly identify and treat as early as possible those patients who are at highest risk of becoming disabled.

METHODOLOGY

The process of developing a predictive model of disability has incorporated two interrelated lines of research. One is the development of a multi-attribute utility (MAU) model to predict low-back disability [8]. This has involved the selection and successive refinements of a list of disability risk factors. The second is the development of a comprehensive and reliable information-gathering system. To this end, a computerized questionnaire reflecting factors in the model has been designed.

Model Development

Identification of the factors which characterize the differences between the disabled and the non-disabled was the first step towards predicting disability in individuals with LBP. In order to identify these factors, a method combining expert opinion and a review of the literature was used to develop a multi-attribute utility (MAU) model to predict disability.

A review of the literature and a retrospective analysis of a previously-collected set of data were used to identify factors relevant to LBP disability. The data consisted of physical and psychological measurements of a subset of 331 males seen at a general health-care facility in Vermont [3,7]. Next, a panel of experts on chronic pain and disability was convened. The panel evaluated and modified the list of factors derived from the literature and retrospective data analysis. The initial list determined by the panel was composed of 108 factors grouped into eight categories (job, psychosocial, injury, diagnostic, demographic, medical history, health behaviors and anthropometric). The list was reduced to 28 factors by eliminating redundancies, interdependencies among the factors, and regrouping some of them. The experts then assigned weights to each of the factors. Factors thought to be more predictive of disability were assigned higher values.

Next, the researchers created a series of fictitious, although plausible, case histories that incorporated the various factors that the panelists had judged were predictive of low back disability. Each of these histories was reviewed by the panel and ranked to indicate relative likelihood of disability. In order to assess the reliability of the model, rankings from each panelist were compared to rankings predicted by the model and also to rankings by the other panel members. Close agreement among the panelist's rankings, as well as between the model and the panelists, was evidence of the reliability of the model.

The advantage of such a methodology is that a highly complex, multivariate set of data can be reduced to a manageable set of factors, which can be tested using a relatively small number of patients. The obvious disadvantages are that the variables may be inappropriately weighted or a number of significant variables may be omitted because of the panelists' biases. For this reason, empirical analyses utilizing discriminant function analyses (DFA), were performed for comparison purposes. Using DFA, factor weights are determined empirically by the data.

Data collection

All patients with back pain who were new to the Vermont Low Back Clinic and between the ages of 18 and 65 were considered for the study. However, patients who were unemployed for more than 3 months, or who had never worked, were considered ineligible. Prior to their appointment with a physician, patients that were considered eligible for the study completed a computerized questionnaire that incorporated the factors in the model. A touchscreen computer was selected so that patients could answer questions directly on the computer by simply touching the screen to select a response. The advantages to this method were several [9]; most importantly, neither the ability to type nor familiarity with computers was required. After examining each patient, the attending physician completed a list of questions that assessed other factors in the model which could not be answered by the patient. Additionally, the physician was asked to predict whether the patient's functional recovery from the low back pain episode would be favorable (i.e., the patient would be working in six months) or unfavorable (i.e., not working in six months). A predicted disability score was calculated, according to the model developed by the panel, based on the information obtained from the patient and the physician.

Six months after questionnaire administration, patients were contacted by telephone to determine work status. Patients who were not holding a job at the follow-up point were classified as "disabled", whereas all others were classified as "working." The group, "working", thus may have included some patients on sick leave. Of the 99 patients who met the study criteria, 92 were reached for follow-up at the six-month point.

RESULTS

When predicting disability using a dichotomous outcome classification of "disabled" or "working", the presence of disability can be regarded as a "positive" finding, whereas the absence of disability (i.e., the patient works) can be regarded as a "negative" finding. The misclassification error that occurs when a patient is predicted to be working, but actually is disabled is described as a false negative (FN), and the percentage of patients thus classified (incorrectly) as working is designated P(FN). In a similar manner, the misclassification error made when a patient is incorrectly classified as disabled (predicted to be disabled, but actually working) is defined as a false positive (FP).

To develop a model that minimizes classification errors, the data were analyzed by comparing outcome predicted by three sources: predictions by physicians, predictions based on the model developed by the panel of experts, and predictions based on a model made of the same factors as the panel of experts model but with the weights empirically derived from the data.

Physicians' Predictions

The physicians detected 54.5 % of the patients who later become disabled, and correctly classified 84% of all patients (Table 1). In total , they predicted 17% of the patients would be disabled after six months. These classification results were viewed as baseline rates against which the performance of the expert and empirical models were compared. It is important to note that the physicians who participated in this study are experts in the treatment of low back disorders. It follows that the accuracy of their predictions would reflect this knowledge and would be greater than that of primary care physicians.

Table 1. Physicians' prediction of disability showing classification terminology.

			PREDICTED	
		N	WORKING	DISABLED
ACTUAL	WORKING	70 (100%)	62 (88.6%) TRUE NEGATIVES (TN)	8 (11.4%) FALSE POSITIVES (FP)
	DISABLED	11 (100%)	5 (45.5%) FALSE NEGATIVES (FN)	6 (54.5%) TRUE POSITIVES (TP)

83.95% Correctly classified

Expert Model

For the expert model, several classification schemes are possible depending on which value of the predicted disability score calculated by the model was chosen as the minimum value indicating disability. All patients with scores above a minimum cutoff value were classified as disabled; those patients with scores falling below the cutoff value were classified as working. The best classification rate yielded 89.1% correctly classified and a total of 7.6% predicted to be disabled (Table 2).

Table 2. Classification rates as maximized by expert model.

			PREDICTED	
		N	WORKING	DISABLED
ACTUAL	WORKING	79 (100%)	77 (97.5%)	2 (2.5%)
	DISABLED	13 (100%)	8 (61.5%)	5 (38.5%)

89.1% Correctly classified
Cutoff value = 0.50

Empirical Model

Discriminant function analysis (DFA) was used in order to validate the weights of the factors used in the expert model and to determine the smallest number of factors that were needed to obtain accurate disability predictions. Actual work status six months following initial data collection was used as the dependent variable. The DFA then assigned weights to the factors empirically.

Because data on some job factors were missing for some patients, these factors were combined into one score. This combined group of factors was the most predictive factor in the empirical model. However, the demographic factor of educational level, when entered into the equation, increased the total percent correctly classified to 88.0% (Table 3).

Table 3. Classification rates as maximized by empirical model.

			PREDICTED	
		N	WORKING	DISABLED
ACTUAL	WORKING	79 (100%)	72 (91.1%)	7 (8.9%)
	DISABLED	13 (100%)	4 (30.8%)	9 (69.2%)

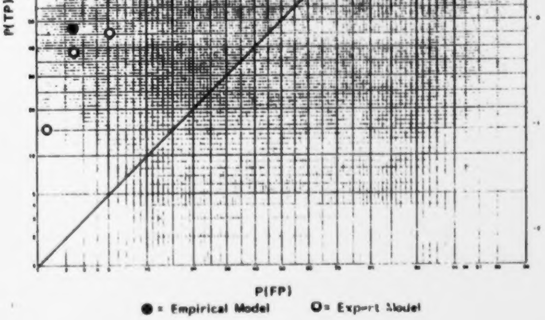
88.0% Correctly classified

Comparison of Models

The performance of the various models were compared graphically (Figure 1). The set of points plotted for the expert model are the classification rates which correspond to successively increasing values (from 0.05 to 0.80) of the predictive risk score calculated by the model. Similarly, the points plotted for the empirical model correspond to successively increasing values of the linear discriminant function score. Because the classification scheme determined by the physicians does not have a range of values based on varying cutoff points, and thus could be represented by a single point only, physician classification data have been omitted from this graphical comparison.

The preferred classification method is one represented by a curve closest to the upper left corner of the graph. This is the range in which both the P(FP) and P(FN) misclassification errors are small.

Figure 1. Graphical comparison of expert- and empirical-based models of LBP disability.



DISCUSSION AND CONCLUSIONS

The comparison of the expert and empirical models shows that the empirical model outperforms the expert model. Both forms of the model are based on the same set of factors, but with factor weights derived in different manners. Therefore, it is not surprising that the DFA model performed better since the weights for this model were derived statistically based on this sample.

Of particular interest is that this panel of experts in low back pain and disability correctly identified a set of factors which, when combined, yield a highly accurate prediction of disability. Moreover, predictions based on the expert model yield an overall percent of accuracy (89.1% correctly classified) comparable to the best of the empirical models. The most important difference appears to be that the empirical method results in fewer misclassifications of patients who do become disabled. Thus, it could be argued that the panel, while using the correct information to arrive at their predictions, may have combined that information suboptimally.

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DETERMINATION OF BODY SEGMENT INERTIAL PROPERTIES

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ABSTRACT

Methods are discussed for determining patient-specific body segment inertial properties using computed tomography (CT) and magnetic resonance imaging (MRI). The image processing techniques and numerical methods for determining the body segment parameters (BSP's) are described. BSP's calculated using the CT and MRI methods were compared to results obtained from classical experimental methods for verification.

INTRODUCTION

Computer-aided design is a process that synergistically links human cognitive and creative skills with a computer's ability to perform rapid analyses of complex systems. The designer and computer communicate through a graphics device that allows the designer to manipulate the system and view the results of the changes. Computer-aided design thus allows the engineer to iterate to the desired solution. Some researchers have proposed that an analogous system, termed computer-aided surgical simulation, be developed for orthopedic surgery (1).

To date, computer-aided surgery has been restricted to geometric manipulations of skeletal structures for reconstructive surgery (2). In order for computer-aided surgical simulation to become more useful to orthopedic surgeons, further tools must to be developed to incorporate kinematic and dynamic models into analyses that predict the functional outcome of surgical procedures. One such tool needed is the determination of accurate patient-specific BSP's. For example, three-dimensional muscle models which distribute resultant joint forces among individual participating muscles using various optimization criteria have been developed (3,4). However, Patriarco (4) demonstrated that predictions of individual muscle forces were influenced much more by the precision achieved in measuring BSP's and kinematic data (and by correct modeling of musculoskeletal anatomy) than by the particular optimization criterion used. If such models are to become part of a computer-aided surgical simulation, an accurate means of determining patient-specific BSP's and musculoskeletal anatomy is required.

Currently, insufficient information on BSP's and the lack of a method for easily determining patient-specific BSP's *in vivo*, especially for pathological and pediatric cases, forces most researchers to use scaling methods taken from cadaver studies of limited applicability (5). But the information necessary to calculate the inertial properties of a subject is contained in the same serial CT or MRI scans which are used to generate the computer graphics models for computer-aided surgical simulation (6). In this investigation, methods were developed and verified to calculate BSP's using CT and MRI imaging modalities.

BACKGROUND

The CT method for calculating BSP's is based upon the principle that x-ray attenuation is approximately linearly proportional to the tissue density. A CT image file is a two-dimensional array of CT numbers. The CT numbers are converted to density values using a linear interpolation scheme proposed by Huang (7):

$$\rho_{tissue} = A \times CT_{tissue} + B$$

where

$$A = (\rho_{water} - \rho_{air}) / (CT_{water} - CT_{air})$$

$$B = ((\rho_{water} - \rho_{air}) / (CT_{water} - CT_{air})) \times CT_{air} + \rho_{air}$$

The serial CT scans are converted to a three-dimensional density array and the BSP's can be calculated by converting the volume integral to a triple summation and numerically integrating the discrete density values over the entire array; e.g., for determining the mass,

$$\text{mass} = \iiint \rho(x,y,z)\, dx\, dy\, dz$$

$$= \sum_i \sum_j \sum_k \rho_{ijk}\, \Delta x\, \Delta y\, \Delta z$$

where k remains constant for any given scan.

MRI does not provide such a linear relationship between scan numbers and tissue density as exists for CT. MRI scans must first be contoured to identify regions of bone, muscle, fat, or skin. These contours are needed to construct the computer graphics model for the computer-aided surgical simulation and can also be used to calculate the BSP's. For compactness of storage, the contours are decomposed into Fourier descriptors using a

Fourier transform and stored as a truncated Fourier series (8). The Fourier reconstruction of the contour is calculated using this truncated series. (The relative error introduced into the inertial properties by using a truncated Fourier series reconstruction can be seen in Figure 1.) Inertial properties of the contoured regions can then be determined by applying Green's theorem and performing contour integrals of the appropriate functions. This process can be demonstrated for calculating the mass for any given region assuming a constant density within the region.

$$\text{mass} = \Delta z \iint \rho(x,y,z)\, dx\, dy$$

$$= \Delta z \times \rho \oint -y\, dx$$

$$= (\rho \times \Delta z/2) \sum_{i=1}^{256} -(y_{i+1}+y_i)(x_{i+1}-x_i)$$

By contouring the appropriate regions of each cross-section and assuming appropriate densities, the inertial properties for any given scan can be calculated using composite body methods.

METHODS

The verification experiments were conducted on a cadaver leg sealed in a plexiglas tube. Two specimens were tested. The computerized tomography was performed on a General Electric 9800 CT Scanner and a Technicare 1440 CT Scanner with 1 cm slices taken every 2 cm over the entire length of the specimen. The magnetic resonance imaging was performed on a Technicare Teslacon NMR Imager with similar protocols. The data processing was conducted on a DEC MicroVax II microcomputer equipped with a DEC VR260 workstation for image processing, a DEC TS05 tape drive for reading scan tapes, and a RA81 disk drive for data storage.

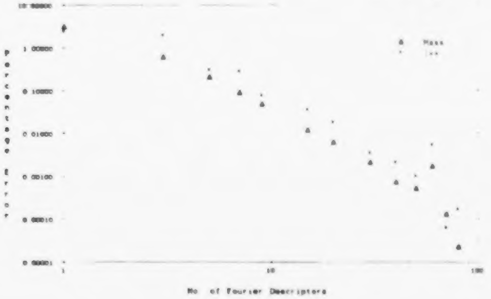

Figure 1 – Relative error of BSP's versus number of terms in truncated Fourier series.

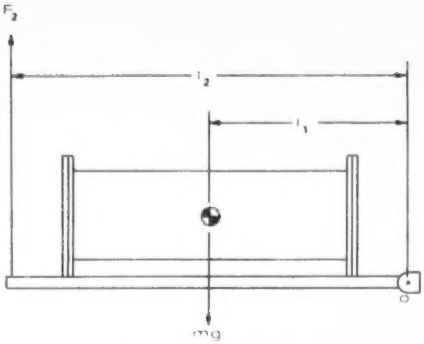

Figure 2 – Diagram of reaction board method for determining center of mass.

Classical methods were used to verify the computed BSP's. The mass was determined by weighing the specimen. The center of gravity was determined using the reaction board method as schematized in Figure 2. A simple moment balance about the pivot of the reaction board results in the following equation for the distance to the mass center:

$$l_1 = F_2\, l_2 / m\, g$$

A pendulum method was used for determining the moments of inertia. Figure 3 is a schematic of the pendulum system. Applying Newton's third law of motion results in the differential equation:

$$I\, d^2\Theta/dt^2 + m\, g\, l_{cg} \sin\Theta = 0$$

which can be linearized for small motions.

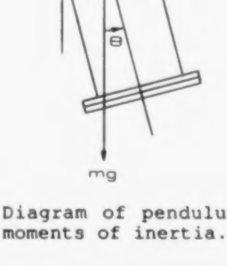

Figure 3 – Diagram of pendulum method for determining moments of inertia.

The moment of inertia can then be determined from the measured period of oscillation.

$$I = m\, g\, l_{cg}\, P^2 / 4\Pi^2$$

The full inertia tensor can be determined by calculating the products of inertia, which can be determined from the moments of inertia about three independent axes in the same plane using Mohr's circle (Figures 4a, 4b). Standard error propagation techniques were used to quantify the error bounds on the experimental results used for verification.

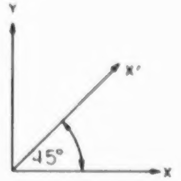

Figure 4a – Axis orientation for determining products of inertia.

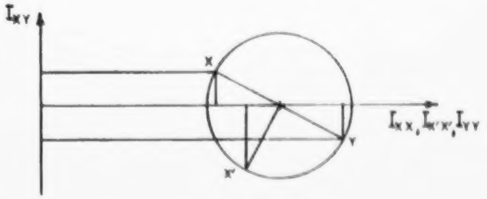

Figure 4b – Use of Mohr's circle for determining products of inertia:
$I_{xy} = (I_{xx}+I_{yy})/2 - I_{x'x'}$

RESULTS

Verification of the CT and MRI methods for determining the BSP's was conducted on cadaveric specimens. The results indicate that the methods developed will be able to provide the patient-specific body segment parameters necessary for computer-aided surgical simulation and other dynamic estimates based on movement kinematics.

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SKIN RESPONSE TO PRESSURE LOADING BY THE BENT FINGER TECHNIQUE

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ABSTRACT

The phenomenon of blanching of the skin associated with the bending of a knuckle is exploited as a means of investigating the effects of external pressure loading on skin blood flow, as well as the elastic properties of the skin itself. Through the use of dimensionless parameters, it is expected that the results should be applicable to other bony prominences and therefore may relate to the tendency to develop pressure sores.

INTRODUCTION AND BACKGROUND

There is evidence that measurable differences in skin blood flow response to loading can be detected between groups which are known to be prone to pressure sores and those which are not. In a study of spinal cord injured paraplegics and hospitalized geriatric patients vs. healthy, able-bodied young men (1), one third of the seated paraplegic and geriatric subjects showed blood flow occlusion at pressures below 40 mm Hg, whereas none of the seated controls showed occlusion at less than 120 mm Hg. It is expected that the technique presented herein may offer a simple method for detecting differences in response to pressure loading which should relate to the tendency to develop pressure sores.

When a finger is bent at the knuckle, we notice that skin blanching occurs over the knuckle at a specific angle of bend for any individual. This phenomenon is related to the blanching brought about by external pressure such as sitting, since both produce a shutdown of capillary blood flow over a bony prominence. The phenomenon in the finger is also related to the classical engineering problem of the tension in a pulley cable, in which the tension is balanced by a corresponding outward pressure provided by the pulley. In the case of the finger, the tension in the skin produces a corresponding pressure on the knuckle itself. Further, the known mathematical solution of the pulley problem gives us specific formulas which should allow us to study elastic behavior of the skin and blood flow response to loading without measuring either the loading or the blood flow itself. The proposed bent knuckle technique has the additional advantage that no instrumentation need be introduced which might distort the desired measurements.

METHODS

If we assume that the skin over the knuckle behaves as a thin, two-dimensional membrane of linear elastic properties and that the knuckle takes a circular shape under the skin, then the pulley problem (2) gives us specific formulas which show that the ratio of applied pressure p to elastic modulus E of the skin is equal to the product of the ratios of skin elongation Δl to initial length l_0 and of skin thickness h to radius of curvature R. Mathematically, this is expressed as

$$p/E = (\Delta l/l_0)(h/R)$$

The assumption of linear elastic properties for the skin is not really a good one at large angles (3), but the assumption of a circular shape over the knuckle is surprisingly good, since the distal end of the proximal phalange is circular at the outside edges and the skin stretches over it as the distal phalange moves during bending. All in all, it seems to be a reasonable model for the bent finger.

But the skin over the unbent finger may be thought of as a wrinkled string. That is, it takes only a negligible tension force to straighten the string, after which it behaves elastically, with the applied force proportional to displacement. Therefore, we must determine the initial skin length l_0 (at which the wrinkles disappear) in order to calculate the elongation Δl.

Note that the angle of bend does not appear in the above equation. But, by making our measurements at the angle at which blanching first occurs, we can calculate the corresponding value of the nondimensional pressure loading p/E for blanching and hence for skin blood flow occlusion. Furthermore, according to dimensional analysis (4), this nondimensional relationship should apply to other bony prominences, despite differences in dimensions and elastic behavior! Dimensional analysis is the engineering technique which tells us how to group the variables we are dealing with so that the resulting relationships are in nondimensional form and are therfore general and do not depend on the particular dimensions or numerical values of the particular case being considered. Thus, since the equation discussed above is expressed in terms of dimensionless ratios, the results apply to any bony prominence which satisfies the assumptions.

The necessary measurements of skin elongation are made with the use of a finger goniometer. With the angle set to zero, two ink marks are made on the dorsal skin surface at a preselected initial length (4 cm) which spans the knuckle. Measurements of length between the ink marks are then made for each selected angle of bend, using a flexible scale which is secured to the skin at the proximal ink mark but is permitted to slide relative to the distal mark. Knuckle whitening is determined by measuring the angle at which the knuckle first becomes whitened between two wrinkles over its entire width.

Measurements of skin thickness and radius of curvature are made by submerging the finger in a water tank, bending the finger to specified angles, and using high-frequency, short range echo doppler equipment (Diasonics DRF-1). A specially designed submersible fixture is used to fix both the angle of bend and the position of the finger relative to the ultrasound probe (see Figure 1, next page). The temperature of the water bath is adjusted to approximate room skin temperature at 30 degrees C.

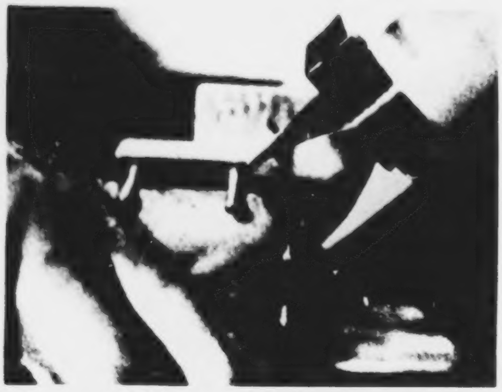

Figure 1. Finger fixture setup for ultrasound pictures in waterbath.

Because of the fuzziness of the ultrasound image at the edges of the skin (Fig. 2), a number of points are digitized directly from the film and then curve-fitted using a least squares fit to two concentric circles of unknown center and radii.

The computer program then gives us the radius of curvature and the skin thickness. It was found that the fit to a circle is excellent if we use points lying on the outer edge of the skin surface. Only a few points are taken on the inner surface to determine thickness.

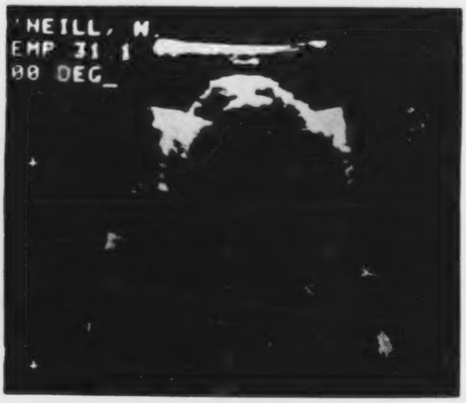

Figure 2. Typical ultrasound picture showing skin thickness and curvature at 100 degrees of knuckle bend.

RESULTS AND DISCUSSION

Calculations made from our measurements to date indicate that the nondimensional elongation of the skin for blood flow occlusion in able-bodied subjects is on the order of 0.07, which agrees well with values obtained by experiments in which uniaxial tension is applied to the outer suface of the skin (5). The nondimensional ratio of pressure to elastic modulus at occlusion is found to be about 0.02.

An example of the resulting elongation plot is shown in Figure 3. In most cases, we found we could approximate the results reasonably well by fitting two straight lines to the data, and there seems to be a rather abrupt decrease in the slope at some point, which evidently represents the point at which the skin wrinkles are essentially straightened out and the skin begins what we might call pure stretching. This point then defines the "initial" length l_0. It was observed that the knuckle turns white rather suddenly at some larger angle, nearly 90 degrees for most able-bodied subjects.

For the paraplegics, we seemed to find less consistency in the results, with some knuckle whitening occurring at a smaller angle, with considerably more variation, and in some cases markedly higher values of skin elongation. As for the ultrasound measurements, we did not see any really noticeable differences between the able-bodied and paraplegic subjects, and the calculations of p/E were quite similar, although at this point, we have really made complete measurements on only four paraplegic subjects, and there is considerable question of accuracy, especially in the measurement of skin elongation.

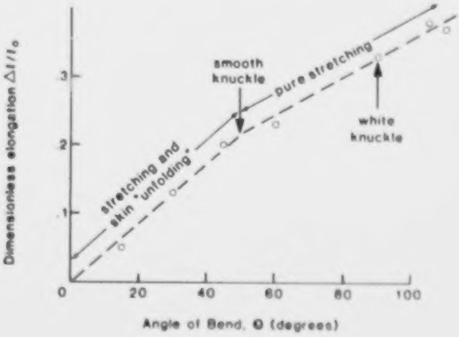

Figure 3. Skin elongation measurements on bent finger of an able-bodied subject.

So far, we have tested only one quadriplegic patient, and here we saw a dramatic difference from the able-bodied group, insofar as the skin elongation measurements are concerned. First of all, we observed that there were NO wrinkles over the knuckle to begin with. Correspondingly, we did not see a clear point at which the curve seems to break, although there was a decrease in slope as the angle of bend was increased. Further, knuckle whitening occurred at an angle of about 70 degrees, as compared with 90 for the able-bodied group. We also found that the slope at the larger angles of bend was substantially steeper than for the able-bodied group. Unfortunately, we were unable to carry out ultrasound measurments because of size of the water tank and the patient's restricted mobility of the hand.

At the present time, we are not satisfied with the degree of scatter in the elongation data, particularly for some fingers which showed considerable enlargment of diameter with bending, since here the scotch tape used to secure one end of the flexible scale seemed to restrict finger extension at the larger angles of bend. Consideration is now being given to the use of two "pins", perpendicular to the outer skin surface, to be secured by small squares of medical tape , and using a silhouette technique to photograph both the angle of bend and the elongation without the use of either goniometer or flexible scale which may inhibit the natural behavior of the skin. Measurements would then be made directly from the silhouette.

Although the results discussed above indicated similar values of the nondimensional parameter p/E for paraplegic and able-bodied subjects, this is not necessarily inconsistent with the results found by Bennett (1) in which the sitting pressures for occlusion were lower for the paraplegics than for able-bodied subjects. These two results are in fact consistent if the modulus of elasticity is lower for the paraplegics, which could result from a lower level of collagen in the skin of paraplegics.

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DIGITAL INTERFACE PRESSURE EVALUATOR

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ABSTRACT

An understanding of the tissue - support interface pressure distribution is necessary for the clinician to effectively choose a body support media. A simply operated interface pressure measureing system has been developed using an electropneumatic sensor and a digital display. A pressure transducer is used to convert the internal sensor pressure to a voltage that is displayed in mmHg. Clinical tests have been performed to asses the value of the device as a clinical tool using normal volunteers and three body support systems.

INTRODUCTION

Pressure sores continue to be a serious complication to the rehabilitation of those with disabilities. These ulcerations often lead to life threatening infections that not only impede but may also destroy previous gain in rehabilitation. Transmission of forces across the soft tissues is necessary when a support system is used to provide functional posture or safe position during healing. The stresses produced within the soft tissues can impair the blood supply and lymphatic drainage near the support interface. Prolonged stress to the tissues will result cell necrosis in and may lead to the eventual development of tissue breakdown and ulceration. Sore formation is almost always near the location of bony prominences. In the recumbent positions and in wheelchair sitting interface pressures at the ischial, sacral, and trochanteric regions is of interest for the determination of proper support. Reswick et al. (1) have determined guidelines for safe magnitudes and durations of pressures at these locations.

One cannot be certain that a support system is effective in reducing the risk of pressure sore formation until an understanding of the load distribution at the tissue - support interface is obtained. To asses individual support need the clinician must collect reliable pressure data. Selection of the weight bearing media and a safe position often depends on reduced pressure at bony prominences and optimal distribution of pressure throughout the support interface.

The interface pressure transducer used in the clinic needs to meet specifications as discribed by Bader et al. (2). Primarily, it should not affect the parameter being measured. Thus the device should be more complient then either the soft tissue or the support media. It must also be durable enough to withstand conditions at the interface, high heat and humidity, yet be flexible enough to be used at curved body contours. Skin pressure evaluating techniques require the transducer to be placed at different anatomical locations as posture and body support media are modified. Thus the pressure sensor element must be easily placed and relocated at the support - tissue interface. A 10 cm diameter single air cell electropneumatic sensor, such as the Scimedics sensor meets most of these specifications. In this system detection of the endpoint, the pressure that causes the loss of electrical contact, is dependent upon the experience of the user. The new digital display pressure evaluating system discribed below eliminates the endpoint detection problem automatically by sampling and displaying the pressure at the instant of lost contact within the flat vinyl air cell sensor.

METHODS

The newly designed digital pressure evaluator was made to be used similar to the existing Scimedics system. The major components of the system are shown in the block diagram in Fig. 1. The single cell electropneumatic sensor from Scimedics is used to determine interface pressure. The pressure within the cell is converted to a voltage by a piezoresistive pressure transducer. This voltage is amplified, digitized, and decoded as a three digit LCD display in mmHg. The relation of the differential voltage produced by the transducer was measured to be linear up to 120 mmHg. When the internal pressure in the sensor exceeds exceeds the externally applied pressure, the electrical contact is lost, the hold circuit is triggered and the displayed pressure value remains for ten seconds or until the external reset is activated. The system is powered by a nine volt battery. When the battery potential falls below a threshold set for reliable operation a voltage monitor turns on a fault indicator light.

The system was calibrated using an analog manometer in parallel with the piezo - resistive transducer of the digital pressure evaluator and a single rubber air cell placed between two fixed surfaces. Internal pressure was adjusted by introducing air into the system using a hand pump and valve. The zero offset and gain of the digital pressure evaluator were adjusted to obtain the best first order polynomial fit (slope = 1.05, S.D.= + 1.64mmHg) for pressures up to 120 mmHg. A calibration curve is shown in Fig. 2. The complete digital pressure evaluating system was tested using the plane surface loading method (3). The air cell sensor was sandwiched between two parallel interconnected flat rubber envelopes that were inflated creating the externally applied load to the sensor. External pressure up to 100 mmHg was measured with the digital pressure evaluator and compared to the applied pressure that was monitored using the analog manometer. Eleven measurements were made with the evaluator for each 15 mmHg increment of applied pressure.

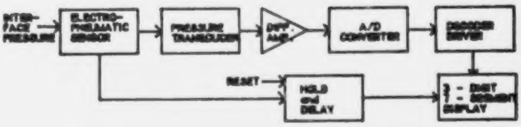

Fig. 1 Block Diagram.

Tissue - support interface pressures were measured by the digital evaluator and the Scimedics evaluator on three normal volunteers. The sacral and trochanteric interface pressures were recorded with the subject in the supine and side lying position. All measurements were repeated three times by relocating the electropneumatic sensor each time. Each subject was tested on three support surfaces; a standard hospital mattress, an air inflated bed cushion (SC-402 Gaymar Industries Inc.,Buffalo N.Y.), and a polyurathane foam bed cushion. Fifty - four independent pressure measurements were made with each device and used for statistical analysis.

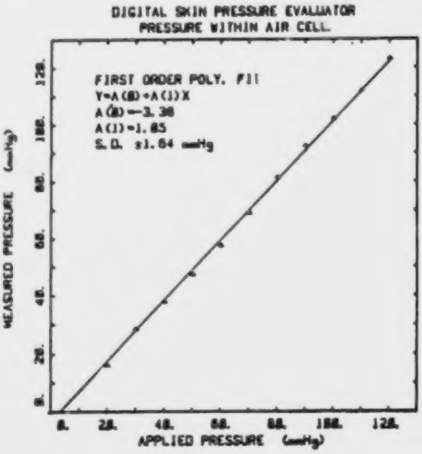

Fig. 2 Calibration Curve.

RESULTS

The reading of the analog manometer monitoring the applied pressure was used as the independent variable and the mean of eleven measurements by the digital evaluator was used as the dependent variable for analysis of the plane surface loading test. The best linear fit for these variables had a slope of 1.08 and a standard deviation of + 1.67 mmHg, confirming the calibration of the piezo - resistive transducer.

Data from the normal subjects were evaluated by the paired comparison t-test. Using the fifty - four pairs of pressure values from the two instruments the null hypothesis of equal mean values from the two instruments was tested. The mean value of the differences was 2.41 + 6.27 mmHg which was indicating a significant diference ($p < 0.05$) between the mean outputs of the instruments. This result may be due to the elimination of of the user error from endpoint detection in the digital system.

CONCLUSIONS

Reliable tissue - support interface pressure measurements are essential for the clinician to effectively design or prescribe a support system for those at risk of pressure sore formation. The digital display pressure evaluator eliminates user error from endpoint detection. The electropneumatic sensor is easy to position and relocate and thus provides for rapid collection of data. The digital device could be provided at a cost that compares to interface pressure evaluators currently available. An effective support system can now be chosen when an understanding of the pressure distribution at the tissue - support interface is obtained. The clinical use of the digital interface pressure evaluator has demonstrated its value as a simply operated, more reliable clinical tool.

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EXPERIMENTAL RESEARCH DESIGNS FOR THE SCIENTIST-PRACTIONER

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ABSTRACT

The systematic evaluation of the interaction between man and technology is of prime importance to the progress of science. Technological advances in the area of assistive devices for persons with varying types of handicaps are progressing at a rapid rate. This rapid growth in technology has resulted in a widening gap between application and data based research. Many reports of the efficacy of technology in advancing human performance are anecdotal and subjective. The purpose of this paper is to provide researchers and clinicians with information about single subject research designs that will increase their efficiency in evaluating the effectiveness of assistive devices. Behavior analysts have developed research designs that allow for the ongoing evaluation of rates of responses, types of contingencies that affect behavior, quality of performance and devices and client performance. These designs are readily applied in clinical settings.

INTRODUCTION

The importance of experimentally assessing the interaction between human behavior and technology cannot be overemphasized. The rapid development of assistive devices designed to augment human performance requires a systematic, data based scientific methodology to ensure future progress in the field. Unfortunately, due to the importance of the scientific rigor required by experimental analysis, many clinicians find it difficult to scientifically assess their clients' responses to technology. It is the contention of this paper that traditional human research designs have prevented the clinician from objectively carrying out research. Before comparing between groups experimental designs with behaviorally based single subject designs, the need for conducting research in man-machine interactions will be discussed.

Of prime importance in the development of technology for handicapped persons is a need for the scientist and practitioner to communicate. Without replicable, data based demonstrations of the efficacy of technology's effect on human performance the concerns of scientist and practitioner cannot be adequately communicated.

Typically, clinical reports of client performance in response to such assistive devices as communication aids, mobility devices, etc., are based on naturalistic observation and anecdotal reporting. This process is inadequate for a number of reasons. Basically, such case studies do not provide specific information concerning training procedures, the progress of skill acquisition, generality to other clients; and are uncontrolled and can be contaminated with the personal bias of the reporter. When considering the importance and testing new devices for handicapped persons, such anecdotal reports, although informative, do not provide adequate scientific information that can be effectively communicated to others. In addition, anecdotally based case studies may not provide sufficient objective information to convince manufacturers to produce large quantities of costly technological devices for the marketplace. Insurance companies faced with increased costs in providing their clients with assistive devices may also be unwilling to fund technology that has not been sufficiently evaluated. Finally, clinicians and scientists alike should ensure that their activities maximally benefit their client population. In order to be effective in the development of assistive devices, it is of paramount importance that such technology clearly augments human performance. This process requires more than subjective reporting based upon clinical observation.

Given the above concerns, this paper outlines some of the reasons more scientifically based research has not been conducted and presents some potential solutions to the problem. The next two sections discuss traditional between group research designs and compares them to single subject research designs based upon behavioral technology.

Group Research Designs

Traditionally, human experimental research has utilized groups of subjects that allow for comparison(s) to be made on some predetermined variable(s). These research designs originated in the late 1940's and early 1950's and were developed by psychologists concerned with the effects of certain therapeutic strategies upon patient populations (1,2). Basically, these research designs utilize two or more groups of subjects that are randomly assigned and are relatively homogeneous. The subjects in each group should be matched on such variables as extent of disability, previous experience with assistive devices, age, sex and any other pertinent characteristic that may influence the outcome of the experiment. In order to perform appropriate statistical analysis, at least 10 subjects per group are required and all the subjects should be assessed over the same time frame. The research itself involves applying some experimental manipulation to one group (experimental group) while not manipulating the subjects in the other group(s) (control group). Consequent to the experiment proper, the averaged scores on the critical variable are calculated and tests of statistical significance are applied. On the basis of this analysis, group differences are determined to be real or not based on a particular level of statistical significance (ie. .05 or .01).

The above group comparison research designs predominate in the experimental analyses of human behavior and its relation to environmental events. The difficulties in using such research designs will now be presented in point form. Many of these points have been discussed elsewhere (1,2,3,4).

1. Due to the specificity of the numerous human disabilities clinicians and researchers are assessing for technological devices, obtaining large numbers of subjects (20 or more) is very difficult in most clinical settings.

2. In hand with the above, it is very difficult to obtain large numbers of experimental subjects that are homogeneous.

3. Average scores obtained from group data do not allow for the assessment of individual subject responses to the critical experimental variable. Although there may be a statistically significant difference between groups, there is also a high degree of variability between subjects within their respective groups. This fact makes it difficult to generalize the results of between group research designs to the specific needs of individual clients.

4. Since the subjects in the control group may not benefit from a potentially positive experimental manipulation, ethical questions arise concerning such research.

5. The research subjects in all of the groups must remain in the experiment until a predetermined length of time has passed. This criterion does not allow for the assessment of rate of acquisition, the developmental course of the acquired skill or critical response, or the possibility that deterioration of a critical variable occured due to the length of the study. Finally, drop-out rates can be high when subjects are required to participate for extended periods of time.

6. The extensive analyses of data generated by large group design experiments places additional pressure on clinicians, who, in most cases, have a wide variety of responsibilities.

Considering all of the above, traditional between group research designs used to assess human performance are not easily utilized by clinicians. During the last thirty years, behaviorists have developed a number of single subject research designs that circumvent many of the difficulties inherent in group designs.

Coincident with the development of behavior therapy as a meaningful therapeutic strategy to alter human behavior, serious reconsideration of scientific research with single subjects began to appear in the 1960's. Of prime importance to this development was the animal laboratory work of B.F. Skinner and his colleagues. Rejecting group research designs, behaviorally based single subject research designs using repeated measurements of overt responses began to appear in applied journals; most importantly, the Journal of the Experimental Analysis of Behavior and the Journal of Applied Behavior Analysis.

In his pioneering work, Sidman (4) laid the groundwork for applied researchers to conduct single subject experiments with their client populations. Since that time, applied behavior analysts have refined and developed numerous single subject research methodologies. It is not within the scope of the present paper to discuss all of these research designs. However, the rationale for such research and two designs of particular applicability to those cncerned with Technology and human behavior will be discussed.

Single Subject Research Designs

Questions of particular importance in applied research relate to cause-effects relationships and the generality of findings. Two specific single subject research designs that have been developed by behaviorists approach solutions to these two particular areas of concern. Both designs address the issue of intrasubject and intersubject variability in assessing cause-effect functional relationships and the process of generality through replication.

The first design to be discussed is the withdrawal design (A-B-A-B). In this particular design, a well defined overt behavior (e.g. number of switch hits, response latency, etc.) is measured under standard conditions with no manipulatio (phase A). When the measured response indicates stability aross testing sessions, the second phase (B) is applied to the experimental subject. Phase B involves the application of some variable that is under investigation (e.g. sound feedback, social feedback, training methods, etc.). Consequent to the demonstration of acquisition, the subject is returned to phase A. This phase should approximate a return of the performance found under the initial phase A. Results of this nature would support the effect of phase B upon the subject as being critical to the behavior change. As such, a cause-effect relationship between the behavior being measured and the variable of scientific concern would be demonstrated. The fourth phase (phase B) would be a further demonstration that the variable under study had a controlling effect on the behavior. This method allows applied researchers to demonstrate the effects of critical experimental manipulations on their subjects as well as to assess the variability of such effects through replication of the design with further single subjects. The measurement of such variability through systematic replication allows researchers to tailor specific interventions for their clients.

The second behaviorally based research design to be discussed is called the multiple baseline. There are two variations of the multiple baseline design that are readily applicable to those involved in assessing handicapped persons with assistive devices.

The multiple baseline design across behaviors involves identifying different responses (usually three) of concern within a single subject. For example, a researcher may be concerned with assessing a training program using a communication board. The variables to be measured may include, number of questions asked by a subject, questions answered and length of time required to respond. These three behaviors would be simultaneously measured under baseline conditions against which a training procedure can be evaluated. Consequent to the baseline phase each behavior is subjected to the training program in a successive order. While the first behavior is being assessed for change as a result of training the other two behaviors remain on baseline. After a period of time has lapsed (usually five sessions) the second behavior is exposed to training and so forth.

The second design is called a multiple baseline across subjects. This design requires a minimum of three subjects. The design involves the simultaneous measurement of at least one behavioral response in all three subjects during baseline. Keeping all other conditions standard, consequent to baseline the experimental manipulation of interest is first applied to subject one while the other two subjects remain in the baseline condition. After a time lapse (usually five sessions) the experimental manipulation is applied to the second subject and so forth.

Both of the above designs allow for the continuous measurement of behavior (responses), objective measurement of the subjects level of performance and for evaluating cause-effect relationships between subject performance and experimental manipulation. In addition, since each subject or behavior is assessed independantly of one another under standard conditions, measures of variability are easily obtained. This information allows for making specific changes in the experimental manipulation(s) of interest. Generality of results obtained from one project can be easily assessed by replicating the experiment with other subjects. The designs also allow for easy communicatio between researchers and clinicians concerned with similar research questions. Finally, the designs are comparatively easy to implement in clinical settings and do not have the many drawbacks of between group designs mentioned previously.

DISCUSSION

The thrust of this paper has been to discuss the importance of data based single subject research in the area of technology and human performance. The importance of such research for both the target population and clinician (researcher) has been emphasized. Reasons why clinicians are prone to present their interventions in an anecdotal case study format have been presented with special emphasis placed upon the inadequacies of between group subject experimental designs. Alternatively, a potential solution has been suggested for these difficulties by discussing behaviorally based single subject research designs.

In view of the importance of all of the above, it is highly recommended that serious researchers and clinicians conduct further inquiries into the use of single subject experimental designs. It is hoped that the cursory information contained in this report will generate interest in others to investigate the viability of integrating these research designs into their clinical and research programs.

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EFFECT OF UNILATERAL ARM RESTRAINT ON UPPER EXTREMITY FUNCTION IN CEREBRAL PALSY

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ABSTRACT

This study was designed to determine the effect of restraining the nondominant arm on function of the dominant arm of a child with athetoid cerebral palsy. Using a computer-based arm function evaluator in the sitting position, performance time of shoulder horizontal abduction was computed with and without the restraint. EMG activity of selected muscles was simultaneously monitored by surface electrodes and a multichannel EMG amplifer system. The arm restraint positioned the nondominant arm on the side of the trunk and prevented all abnormal reflex movements at the shoulder of the same arm. Peformance time was less when the arm restraint was applied. Generally, tonic and phasic EMG activity decreased in all the muscles monitored. The results of this study show that upper extremity motor function improved in the dominant arm when the nondominant arm was restrained and that myoelectric activity was not adversely affected when the restraint was applied.

INTRODUCTION

Upper extremity function in children with athetoid cerebral palsy is usually impaired.[2] The time required by a group of children with athetoid cerebral palsy to perform voluntary motor tasks was found to be significantly longer than that required by a similar group with spastic cerebral palsy.[3] This finding was attributed to the presence of prevailing abnormal involuntary neuromuscular activity and consequent movement incoordination. Reducing abnormal involuntary activity in the seating position[4] and providing adequate stability for the trunk which is the base of support for the upper extremity is of primary importance for maximizing residual voluntary motor functions. The use of arm restraint in the seating position is now an important means of achieving this in children with athetosis in our seating clinic. This single subject study is an objective evaluation of the effect of arm restraint on function.

This study measured the time required to perform upper extremity function with and without applied restraint to the nondominant arm. The study had three purposes: (1) to determine the effects of nondominant arm restraint on the function of the dominant arm in a child with athetoid cerebral palsy, (2) to determine and evaluate the effects of such restraint on the myoelectric activity of selected muscles, and (3) to determine possible changes in tonic and phasic activity of these muscles and whether these were being compromised by the restraint.

METHODS

Subjects

The subject was an 8-year-old with a diagnosis of athetoid cerebral palsy. Based on the clinical evaluation conducted by the therapist, the child had fair to good head control, fair trunk control in the seated position, fair to poor gross upper extremity control, and poor fine motor skills on a scale of good, fair, poor and none.

Instrumentation

Arm function was measured as the time required by the child to perform a prescribed upper extremity movement (performance time). Performance time was obtained using a system consisting of a touch-activated switch, an Apple computer, and a video monitor (fig. 1). The switch was mounted on an adjustable lap tray so that it was at the same sagittal plane as the midline of the body and at the same horizontal plane and distance from the xiphisternum. Initial activation of the system by the researcher provided a picture cue to the child on the video monitor to move his dominant arm from a starting position on the tray (shoulder abducted position) to touch and activate the switch (shoulder adducted position). The system, thereafter, automatically provided the cue 0.5 second after each activation. The child was instructed to touch the switch and return his arm to the starting position as quickly as possible without assistance. Performance time was computed as the time between the initial activation of the system and the tenth (and final) activation of the switch.

Myoelectric activity was monitored via surface electrodes and a multichannel EMG amplifer system and a multichannel analog-to-digital converter (A/D).[3]

The nondominant arm was held to the lateral side of the trunk using an arm restraint which consisted of an orthoplast molded to fit the contour of the arm and padded with 1/2-inch thick foam (fig. 1). The restraint was stablized using a trunk belt which was attached to the frame of the backrest. The arm restraint was not incorporated in the tray, but it closely simulated the effects of such a system.

DATA COLLECTION

Bilateral myoelectric activity was obtained from the anterior deltoids (for shoulder horizontal adduction activity), iliocostalis lumborum (for low back extensor activity and trunk stability), and the quadricep muscles (for evaluating distal transference of activity). The skin over each muscle was cleaned with alcohol and a pair of surface electrodes (1 cm diameter Ag-AgCl) with electrode paste was attached to the skin. A ground electrode was attached to the skin over the crest of the tibia.

Six sets of functional performances were obtained with and without the arm restraint from the child. Each set consisted of 10 repetitions of horizontal adduction of the shoulder. Performance time was calculated for each set. The child was allowed a 5-minute rest period after two sets of performances. The sequence of testing with and without restraint for 15 seconds from all selected muscles 5 minutes before commencing functional performance and 5 minutes after all six sets were completed (tonic EMG). EMG data were also simultaneously monitored in all the selected muscles during each functional performance (phasic EMG).

The mean performance time for each set (10 repetitions) was used to compute the overall mean performance time with and without the arm restraint. The mean integrated EMG activity (IEMG) was computed for each muscle (tonic activity was obtained without restraint while phasic activity was obtained with and without restraint).

RESULTS

A mean performance time of 85 seconds was obtained without arm restraint and 62 seconds with arm restraint (fig. 2). The difference in performance times represents a 27.0% decrease with the use of arm restraint. In the deltoid muscle, the highest mean level of IEMG activity of 11.0 µV · S was recorded from the left (nondominant) side during functional performance without arm restraint (fig. 3, deltoid). However, with the arm restrained, mean IEMG activity dropped to 1.9 µV · S in the same muscle. In the back extensor, the highest mean IEMG activity of 1.9 µV · S was recorded on the left iliocostalis lumborum during functional performance with arm restraint and the lowest of 1.2 µV · S recorded on the right side without arm restraint. In the distal body segment, the highest mean IEMG activity of 5.0 µV · S was recorded in the left quadriceps during performance without restraint and the lowest of 2.8 µV · S in the right quardiceps during performance with restraint.

DISCUSSION

The difficulty faced by children with athetoid cerebral palsy in performing voluntary movements is due in part to the presence of abnormal involuntary movements. Because these movements lack any fixed amplitude, rhythm, or direction,[1] attempts at movement reeducation and control of these abnormal movements are often frustrating for both the child and clinician. The results of this study show that performance time of a prescribed upper extremity function improved (lower performance time) when the arm not being used was restrained.

Perhaps motor activity was more isolated and selective when the restraint was applied. Because total EMG activity measured is the sum of the voluntary and involuntary activities, it is reasonable to suggest that there was a decrease in the severity of the abnormal involuntary activity. A decrease in the severity of the abnormal movements allows the individual more control of the voluntary movement being performed because distrations and disruptions to purposeful movements created by these abnormal athetoid movements are lessened.

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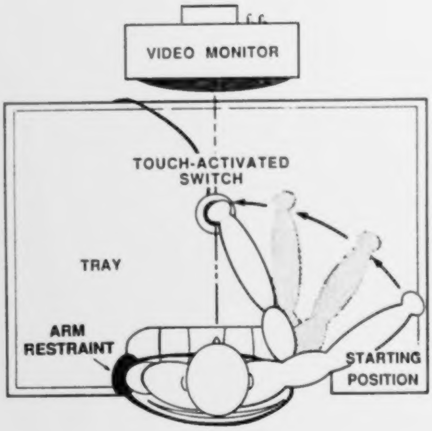

Figure 1. Superior view of child performing upper extremity function

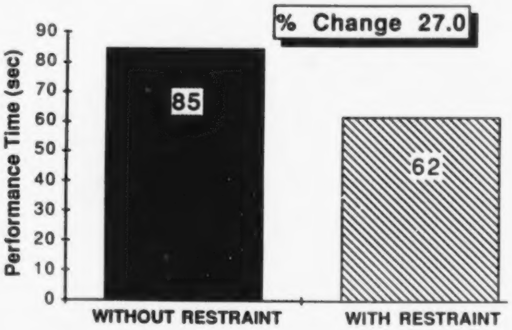

Figure 2. Mean performance time without arm restraint and with arm restraint.

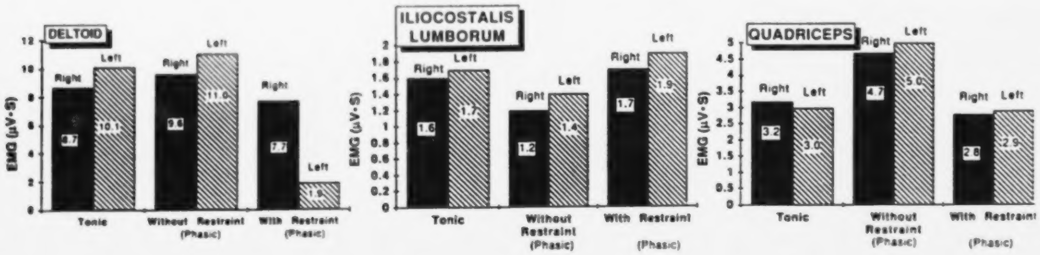

Figure 3. EMG activity in selected muscles with and without arm restraint. The child was right-handed.

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The Design and Use of a Microcomputerized Real-Time Muscle Fatigue Monitor Based on the Median Frequency Shift in the Electromyographic Signal

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ABSTRACT

We have designed a real-time microcomputerized muscle fatigue monitor based on the median frequency shift of the electromyographic signal. This instrument can provide an outcome measure of treatment modalities, and can be diagnostic for the patient undergoing rehabilitation and for the injured athlete. For the subject performing an isotonic and isometric task, preliminary results suggest a repeatable linear decrease in median frequency (MF) of the EMG signal as a function of time.

INTRODUCTION

Through the use of electromyography (EMG), an objective measure of muscle fatigue has a wide range of useful clinical applications. Three broad areas are: (1) the field of ergonomics where the onset of fatigue provides critical information towards matching the worker to the task [2], (2) as a diagnostic tool for neurological disorders [6], and (3) as a measure of a subject's response to athletic training or physical therapy.

We have designed a prototype microcomputerized muscle fatigue monitor. It is based on the downward shift of the median frequency (MF) of the EMG power spectrum [3], measured digitally via the fast fourier transform (FFT). Although other devices exist for computing the MF in real time [e.g., 1,4], our device uses simple off-the-shelf hardware and performs an FFT-based computation of the MF in software, rather than by the use of specialized analog circuitry.

In this paper, we describe the digital muscle fatigue monitor and a preliminary test designed to estimate the repeatability of our technique for measuring muscle fatigue. For an index of fatigue, we have chosen the regression slope (Hz/sec) of the MF versus muscle contraction time [3], generated on two separate days for individuals performing an isometric contraction of their erector spinae muscles, until voluntary task termination.

DEVICE DESCRIPTION

The monitor hardware consists of a microcomputer (IBM PC AT) and attached A/D converter (Tecmar Labmaster) for input of raw amplified EMG. The monitor software was written in compiled BASIC with assembly language subroutines.

The block diagram in Figure 1 shows the signal processing of the EMG signal performed with the muscle fatigue monitor. For each computation of the MF, the software is designed to: (1) sample the EMG data at 512 Hz for a duration of 2 seconds (anti-aliasing 4 pole Butterworth filter at 220 Hz), (2) perform a 1,024 point FFT of the EMG signal, and (3) compute the MF from the FFT data.

The computation of the MF is repeated automatically at a constant time interval (T) selected by the user. For the present prototype one-channel monitor, this interval is generally no less than 6 seconds: 2 seconds of which are taken up by the sampling of the EMG, with the remaining 4 seconds taken up by the FFT and MF computation. A record of MF computation, evenly spaced in time, can thus be computed on-line, during the fatigue activity.

Although sampling rate and sampling duration can be selected by the user within the monitor program, the defaults of 512 Hz and 2 seconds respectively are chosen as a compromise between speed and accuracy of the MF computation. Computation speed is proportional to a factor of at least N log (N), where N is the number of sampled points for the FFT. To minimize computation speed, this either tends to place an upper limit on the sampling duration or to encourage the use of a slower sampling rate. The relatively slow sampling rate of 512 Hz is acceptable for surface EMG and provides 2 seconds of sampled data (for N=1,024), but would have to be increased, probably by a factor of 2, for intramuscular EMG which characteristically carries a higher frequency bandwidth. As processor speed and software design change, these constraints will most likely be reduced.

Once the MF computations are completed, an off-line linear regression of MF versus time is performed within the monitor program to yield a slope (Hz/sec) and a coefficient of determination.

The 6-second minimum time interval may also be a device limitation for muscle contraction times of less than a minute, by providing too few Mf computations ($n < 10$) for a statistically valid regression analysis. So far, this has not been a limitation for our applications involving isometric trunk muscle tasks.

PRELIMINARY USE

Methods. The fatigue monitor has been analyzed using the right and left erector spinae surface EMG signals of 10 subjects performing a Sorensen test on two separate days. For this test, the subject lies face down on a table with only the lower body in contact with the table, and with the upper body suspended horizontally to impose a constant flexion moment about the lumbar spine. Subjects voluntarily maintain this posture until unable to do so any longer.

Results and Discussion. A typical graph of MF versus time, with the regression lines included, is shown in Figure 2 for the right muscle of a sample subject for both days of testing. For this subject, regression slopes between the two days are similar (-.163 and -.158 Hz/sec), despite differences in the initial frequencies (93.2 and 98.8 Hz).

The regression slope of MF versus contraction time was computed separately for the right (R), the left (L), and the sum of right and left (R+L) muscle groups. The R+L computation involved first averaging the MF of the right and left muscles at each moment in time and then computing the regression slope. For the 10 subjects, for both days of testing, and for the right and left muscles analyzed individually (n=40), the coefficient of determination from the linear regressions averaged .782 (±.175).

The Day 1 and Day 2 slopes for the individually analyzed R and L muscles are plotted for each subject in Figure 3. The corresponding R+L slopes are shown in Figure 4. Across subjects, the regression slopes varied from approximately -.050 to -.318 Hz/sec for the R, L, and R+L data. However, with the exception of subject 2, the intrasubject differences between the day 1 and Day 2 slopes were well below the intersubject differences.

In particular, the R+L formulation appears to have the best intrasubject repeatability between days, perhaps because it may be able to account for transient asymmetries in right and left muscle load sharing that could cause asymmetries in right and left muscle fatigue. Other studies have shown the sum of right and left processed EMG to be the best estimator of sagittal plane moments imposed on the spine [5]. By analogy, the R+L formulation may provide the best estimator of muscle fatigue for the Sorensen test, which ideally imposes a pure sagittal plane moment on the subject's spine. To implement the R+L formulation in real time would require expanding the fatigue monitor to two-channel capability with a concomitant increase in FFT and MF computation time. With changes in software design and available hardware, this challenge may be met without increasing the minimum 6-second time interval between data samples.

A coefficient of variation for the separate-day slopes (S) was computed by the following formula:

$$\frac{\mathrm{VAR}_{avg}\,[S_1,S_2]^{\frac{1}{2}}}{S_{avg}} \times 100\%$$

where VAR_{avg} $[S_1,S_2]$ represents the average of the variances between the Day 1 and Day 2 slopes for each subject taken individually (n=10), and S_{avg} represents the average magnitude of the regression slope for both days and all subjects (n=20).

Table 1 shows the coefficients of variation of the R, L and R+L slopes, as well as for the time to voluntary fatigue.

Although we could not find any instrumentation errors with the Day 2 data of subject 2, we suspect these data to be inaccurate because the regression slope resulting from these data is much larger than the average slope for all subjects (-.318 versus an average of -.118 ±.078 Hz/sec). Also, the difference between the Day 1 and Day 2 slopes is much greater for subject 2 than for other subjects (Fig.4). Table 1 therefore also shows the coefficient of variation for the data set with subject 2 excluded. This omission halves the R+L coefficient of variation from 27.4% to 13.9% with similar decreases seen for the other regression slopes. Interestingly, the fatigue time coefficient of variation was the smallest, at roughly 10%. This suggests that time to fatigue is one of the more reliable indicators of a subject's capacity to resist muscle fatigue for a task like the Sorensen test.

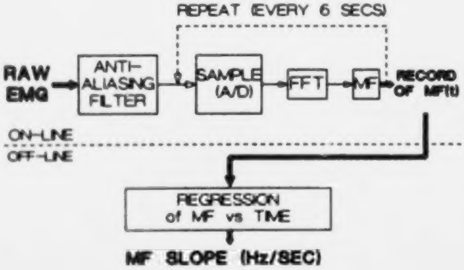

Fig. 1. Signal Processing Block Diagram.

Fig.2 Change in Median Frequency: Subject 1

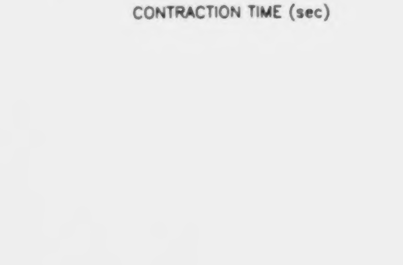

Fig.3 Day 1 & 2 Slopes: R & L Muscles Separate

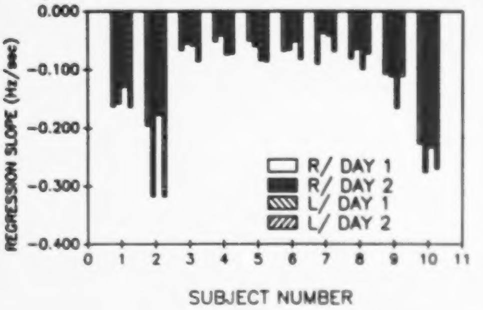

Fig.4 Day 1 & 2 Slopes: R & L Muscles Combined

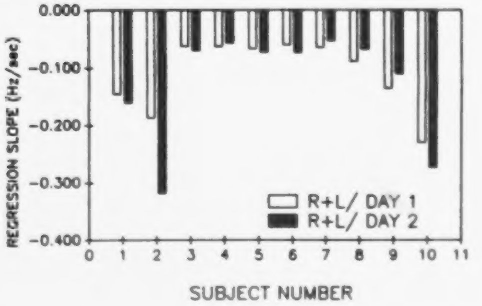

Table 1. Coefficients of Variation

OUTCOME MEASURE	ALL SUBJECTS (n=10)	EXCLUDING SUBJECT 2 (n=9)
R SLOPE	28.3%	18.3%
L SLOPE	30.9%	20.4%
R+L SLOPE	27.4%	13.9%
TIME TO FATIGUE	10.2%	10.5%

CONCLUSIONS

1. A real time muscle fatigue monitor based on the MF shift in the EMG signal has been designed with off-the-shelf hardware and specialized software.
2. The muscle fatigue monitor has been tested for 10 subjects performing an isometric trunk flexion-resist task and has an estimated intra-subject, between-day variability of 14% to 31%, depending on the chosen data reduction techniques and the experimental conditions.
3. Based upon need, the fatigue monitor's future capability may be expanded to provide more channels, faster algorithms for computation of the median frequency, or a shorter time interval between sampled points.

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ACKNOWLEDGEMENT

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A DEVICE AND PROTOCOL TO OBJECTIVELY MEASURE CERVICAL MOTION

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ABSTRACT

Cervical region pathology is a common problem in man with the incidence increasing with age. A major symptom or sign of pathology is loss of motion in one or more planes of movement and usually correlated with pain. Measurement of cervical motion during the course of a therapeutic regimen provides objective data on the benefits of the selected treatment approach. Available devices and methods are time consuming, not well standardized, cumbersome and poorly accepted by practitioners. Recognizing the need for a new device and practitioner education, a measuring device consisting of several components was developed.

The Cervical Range of Motion (CROM) device would be used in the field of medicine to accurately assess movements of the cervical spine in the sagittal (including suboccipital motion), coronal and transverse planes.

INTRODUCTION

The CROM device facilitates the quantification of cervical range of motion (ROM) measurements which currently are rarely documented objectively by practitioners. In a review of 200 Medicare claims on patients treated for spinal dysfunction, only eight per cent provided objective measurements. Commercially available devices for quantifying cervical ROM were obtained for evaluation based on thirteen selected criteria. The CROM device was developed to meet all selected criteria.

The CROM device utilizes gravity goniometers to measure accurately and quickly the angular range of all head and neck movements. The basic configuration of the device is similar to a light-weight eye glass frame and assures easy application and standardization of positioning for measuring neck or cervical flexion/extension, suboccipital flexion/extension and lateral bending (Figure 1).

A third goniometer measures the rotation of the head or cervical spine in a horizontal plane. It is fastened to a shoulder yoke and is manually zeroed when the yoke is connected to the principal CROM frame by means of the flexible steel strap and frontal insertion (Figure 1).

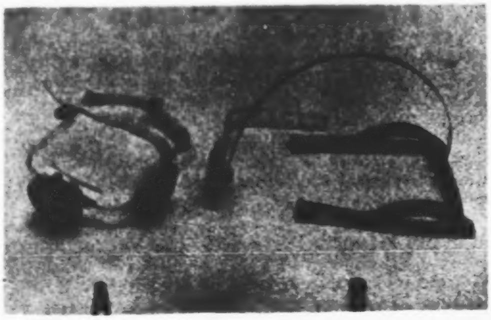

Figure 1

Components of the CROM device. A. Principal frame. B. Auxiliary frame with yoke, flexible steel strap and frontal insertion.

PROTOCOL

Suboccipital flexion/extension

With the subject seated, the principal CROM frame is stabilized by fitting the nosepiece comfortably against the nose and forehead with temple frames resting on the ears and by fastening the two velcro straps. The subject stands facing away from an outside corner or edge of an open door with the sacrum, thoracic spine, and occiput in contact with the wall or door to prevent substitution movements. The examiner demonstrates movements of suboccipital flexion/extension sliding occiput along surface without losing contact or changing pressure with the surface (1). At this time the sagittal plane goniometer is set at zero. The subject moves through his maximum range of suboccipital flexion, and is measured. The subject then moves through his maximum range of suboccipital extension, is measured, and returns to the resting position.

Cervical flexion/extension

For the remaining measurements the subject sits erect in a straight-backed chair with the sacrum against the back of the chair and both feet flat on the floor. The sagittal plane goniometer remains at the same zero position that was used for suboccipital flexion/extension.

The subject is instructed in how to perform cervical flexion and extension. To assure total movement in this multi-joint maneuver the examiner stands behind the chair and lightly places his index fingers in the subjects ears and describes how suboccipital motion is attained by rotating around the ear axis (fingers). Upon completion of full suboccipital flexion motion, the examiner will have the subject continue flexing until full cervical flexion is obtained and measured.

Cervical extension is measured in a similar manner with suboccipital extension first followed by cervical spine extension.

Lateral bending

With the subject looking straight ahead the goniometer in the frontal plane is set at zero. The subject is asked to bend the head to the left, keeping the shoulders level. The examiner prevents shoulder elevation by lightly placing a hand on the right shoulder and manually correcting any motion of the head outside the coronal plane. Measurement is taken and the procedure is duplicated for right lateral bending after first returning the head to the zero starting position. The measurement is recorded after maximum lateral bending to the right.

Rotation

With the subject seated, the auxiliary frame is positioned on the shoulders, yoke fashion, the bar is inserted in the frontal slot of the principal CROM frame and the horizontal goniometer is positioned so as to be in the axis of cervical rotation, approximately in line with the mastoid process (Figure 2). This position is recorded using the scale provided for future reference.

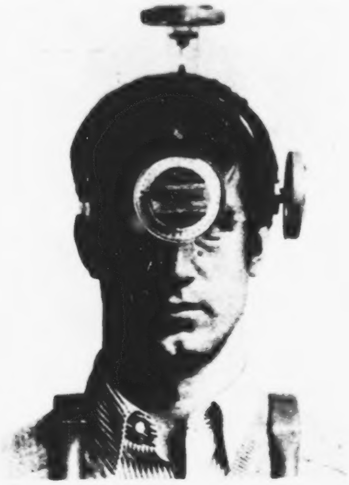

Figure 2

Assembled components of CROM device on a subject.

Following demonstration of the left and right rotation of the head the goniometer is set at zero as the subject looks straight ahead. Following rotation or turning the head to the left, a measurement is recorded and the head is returned to the starting or zero position. Rotation to the right is performed and a measurement recorded thus concluding data collection.

RESULTS

Twelve subjects were randomly selected from students, staff and faculty in the professional programs of physical and occupational therapy at the University of Minnesota. All subjects were considered to be normals. Differences due to the aging process were evident as the ages ranged from 20 to 55 years. Three examiners were involved in testing inter- and intrarater reliability. Rotation measurements were not examined at the time of this study as design modification were in process. A standard protocol was established to assure that extraneous variables were controlled from subject to subject and that each subject received the same instructions and preparations.

Interrater reliability showed slightly greater variability than intrarater reliability analysis with the following results (Table 1).

Table 1. Interrater and Intrarater Reliability

	soflex	*soext*	*flex*	*ext*	*l-lat-b*	*r-lat-b*
Mean ROM						
intra	16.42	29.33	59.00	61.08	41.25	40.75
inter	16.58	33.17	57.17	63.75	41.58	42.25
t test	.16	3.10	.91	.80	.22	1.31
Correlation Coefficient	.76	.87	.79	.82	.83	.93
% of Error (Mean of the differences)	-1.03	-12.16	3.15	-4.28	-.80	-3.61
% of Absolute Error (absolute value of the differences)	18.18	14.94	10.04	13.09	9.66	6.43

Clinically interrater reliability is considered to be reliable if the measurements are within five degrees. In reviewing the data it is seen that the measurement was consistently within those quidelines. With the exception of suboccipital extension, the means for all measurements were within two degrees or less. The measuring does show a difference between testers with one of the examiners measuring consistently greater ROM in subject than the other. All correlations were .755 or greater (0.755-0.934). The percent of error also points to suboccipital extension as being less reliable than other measurements.

DISCUSSION

Numerous protocol and design changes have occurred throughout the development of the CROM device to assure accurate, reproducible values. A modification to the latest protocol is intended to improve suboccipital movement reliability. The multiple articulations between the alanto-occipital joint and C_7 -T_1, provide the potential for significant variability depending on how the subject performs the flexion and extension movement. The described system and protocol will provide an accurate, time-efficient means for quantitatively assessing range of motion of patients with cervical dysfunction and objective information for documentation of patient progress to therapeutic intervention. Utilization of the yoke system for quantification of head/trunk posture is being developed to further compliment the assessment of treatment and patient education outcomes.

The end result will be a system capable of quantifying specific gross movements of the head and cervical spine in three primary planes. It will also provide a mechanism to identify changes in head/trunk posture through serial measurements during the course of treatment and patient education. With improved range of motion and posture as ultimate goals of therapy in patients with spinal dysfunction, the CROM device affords a mechanism for documenting change.

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Supported in part by NIHR Rehabilitation Engineering Center Grant G 008300075. University of Minnesota, Department of Physical Medicine and Rehabilitation, 860 Mayo Building, Box 297 UMHC, Minneapolis, Minnesota 55455.

COMPARATIVE ANALYSIS OF FORWARD AND BACKWARD HUMAN WALKING AND STEPPING

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ABSTRACT

Human gait was studied by comparing the kinematics of: (1) steady-state forward walking, (2) steady-state backward walking, (3) stepping in place, (4) forward gait initiation, and (5) backward gait initiation. Results showed that steady-state forward and backward walking are similar, with events occurring in reverse time sequence. The main distinguishing features that set apart these two locomotory movements were observed in hip and knee angular motions, step length, speed, and movement fluidity. During gait initiation, it appears that the swing leg first flexes at the hip and knee to raise the ankle along a vertical radial line through the hip. The elevation movement, to gain initial floor clearance, is common to initial forward stepping, initial backward stepping, and stepping in place. Data shows that a person returns his foot to the floor along the same line radiating from the hip when walking in place. It also shows that a similar radial movement is made when stepping backward during the latter stage of the step. During this step, extension of the leg appears to move the ankle along a radial line (now directed posteriorly) from the hip.

INTRODUCTION

It has been proposed that studying backward or "retrograde" walking, may provide insight concerning the mechanism of human walking. This kind of study may also prove to be useful in understanding the rehabilitation of certain leg and back injuries which some clinicians are treating with retro exercises. Finally, the study of retrograde walking may be applicable to the field of functional neuromuscular stimulation (FNS). Many daily living activities require backward stepping and so a useful FNS system for retrograde movement might be beneficial.

METHODOLOGY

A 16 mm movie was made in which one healthy 23-year-old male subject walked forward and backward along 70 feet of level, paved, bicycle path. The scenes were later spliced to generate four different walking scenes: (1) forward walking, (2) backward walking, (3) forward walking played in reverse so as to generate backward walking, and (4) backward walking played in reverse so as to generate forward motion. Qualitative observations regarding the similarities and differences of forward and retrograde walking were noted.

Averages for cadence, step length, relative stance time, relative swing time, and walking speed were obtained for eight healthy subjects between the ages of 23 and 55. These parameters were measured using a 22.5 meter long walkway constructed from Velostat^{TM}, an electrical conducting material. The subjects wore electrical conductors on their shoes that were connected to a 9-volt battery source. Stride information came from a measure of the potential created across the length of the conducting walkway when both feet were contacting it (1).

Joint angle measurements of the leg were obtained from six healthy subjects between the ages of 24 and 45. Five 0.75 in. diameter hemispherical markers were covered with Scotchlite^{TM}, a retro-reflective material. The markers were placed on the greater trochanter, lateral femoral condyle, lateral malleolus, heel, and fifth metatarsal phalangeal joint. Strobed data was recorded of each subject walking forward, walking backward, stepping in place, initiating forward gait, and initiating backward gait. Hip, knee, and ankle position data were collected from the videotape and transferred to the screen of a Macintosh computer which computed the angular relationships.

RESULTS

Movie Results The movie comparing forward (F), backward (B), forward but played in reverse (FREV), and backward but played in reverse (BREV) revealed several differences between forward and retrograde walking. The most striking difference was noted in the BREV scene. The subject's arm swings were not always synchronized with the leg movements in the normally expected fashion. Instead of opposite sided appendages pairing together (i.e. right arm swings forward as left leg swings forward), the arm swings were irregular and sometimes out of phase with the legs. Upon comparing the BREV and F scenes, it was noted that there was more hip and knee flexion during forward walking. The subject's posture also appeared to be more erect when walking backwards. Generally, the F and BREV scenes differed in that BREV displayed more stiff and stilted movements, whereas F showed more smoothly flowing motions.

Gait Parameters The average percent stance phase was 62.4 ± 2.1% for forward and 62.0 ± 2.8% for backward walking. In all eight cases, the speeds and step lengths decreased during retrograde walking. The cadences, however, varied according to each subject tested.

Angular Displacement Data The data is presented in the form of angle-angle diagrams, which show both hip and knee angles simultaneously. Each point represents 1/30 sec. separation time. Figure 1 shows the hip-knee angle-angle diagram for a single subject during a steady-state forward step cycle and figure 2 shows the corresponding plot for a steady-state backward step. The data presented was found to be representative of the six subjects tested. Toe-off (T.O.), heel strike (H.S.), toe strike (T.S.), heel-off (H.O.), and the direction of time progression are indicated in the figures. Soon after H.S., in (F), the knee undergoes a small flexion of approximately 22 degrees while the hip extends. The knee straightens before undergoing a second flexion wave of 74 degrees.

Figure 2, for (B), shows a somewhat similar trajectory, but the knee angle does not undergo an initial knee flexion directly after T.S. Ankle data, however, showed that the ankle sharply flexes after T.S., so it appears that ankle flexion compensates for knee action during retrograde walking. Additional data from the other subjects also support the idea that shock absorption is predominately through the knee and ankle for forward walking and through the ankle for backward walking.

The angle-angle diagrams for an initial forward step, initial backward step, and a step in place are shown in figures 3, 4, and 5. The starting point for all three curves lies near zero degree hip flexion and 10 degrees knee flexion. The curves then proceed clockwise for forward and counterclockwise for backward initial steps. The trajectory for stepping in place shows the same linear travel path throughout the full cycle. The initial linear sections in figures 3, 4, and 5 all have slopes of about 1.8, which suggest that the knee flexes approximately two times as much as the hip until T.O.

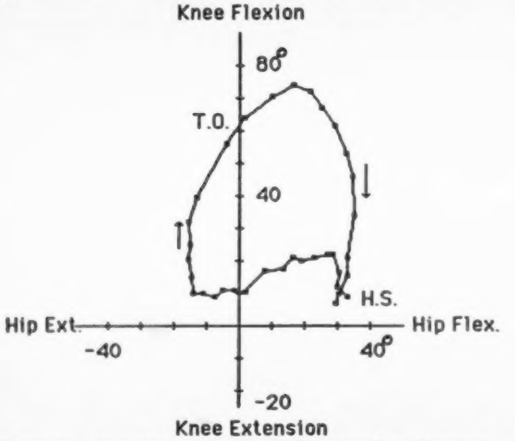

Figure 1: Hip-Knee Angle-Angle Diagram for a Forward Step During Steady-State Walking (Subj. R.C.). Heel strike (H.S.), toe-off (T.O.), and the direction of progression are indicated.

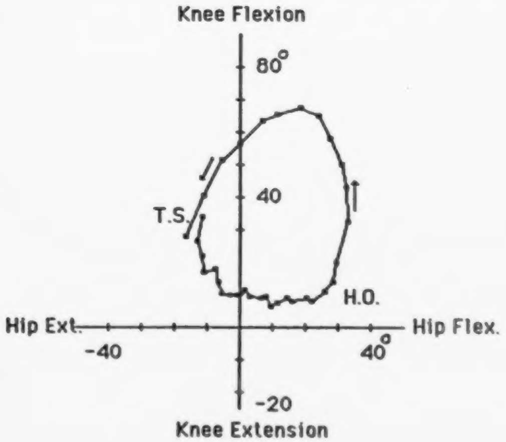

Figure 2: Hip-Knee Angle-Angle Diagram for a Backward Step During Steady-State Walking (Subj. R.C.). Toe strike (T.S.), heel-off (H.O.), and the direction of progression are indicated.

In a rigid two link model (figure 6), the relationship between hip and knee angles was explored as the terminal point Z moves vertically upward toward the anchored point O. Substituting actual leg (thigh and shank) lengths for A and C, simulated angle data was generated for various lengths B and the resulting angular relationship was found to accurately describe the experimental data. This model suggests that the heel moves along a straight path toward the hip prior to T.O. during forward initiation, backward initiation, and stepping in place. The initial backward step exhibits a "U-shaped" hip-knee curve whose last phase is linear and approximately parallel to the first phase. Since the last phase's curve runs parallel to that of the first, it is logical to assume that the foot is being lowered to the ground along another radial path, away from the hip. The parallel displacement is present because the radial line from the hip is no longer vertical, but rather at a specific angle.

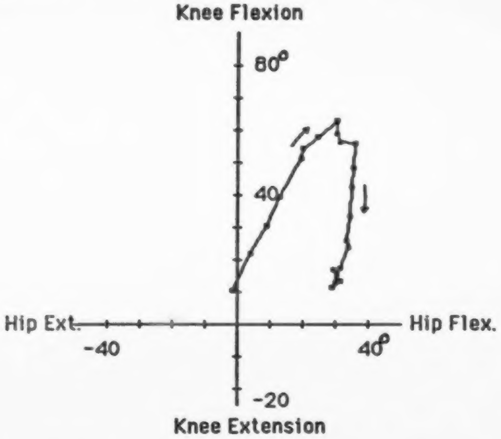

Figure 3: Hip-Knee Angle-Angle Diagram for an Initial Forward Step (Subj. R.C.). Initial hip at zero degrees and knee at 10 degrees. The plot proceeds clockwise.

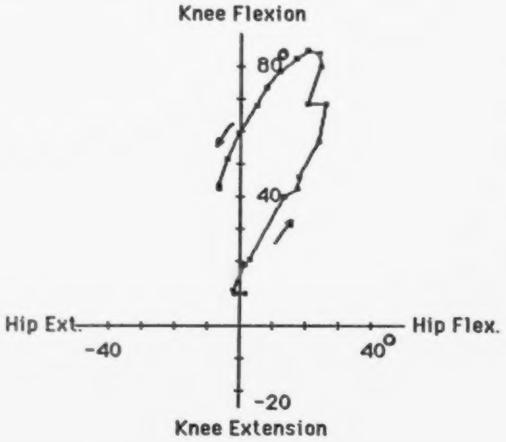

Figure 4: Hip-Knee Angle-Angle Diagram for an Initial Backward Step (Subj. R.C.). The plot proceeds counter-clockwise.

CONCLUSION

Retrograde walking and gait initiation have received relatively little attention compared with steady-state walking. This study has shown some of the kinematic relationships that relate forward walking, retrograde walking, walking in place, and gait initiation. The results support the data of Thorstensson (3), who studied forward and backward walking on a treadmill.

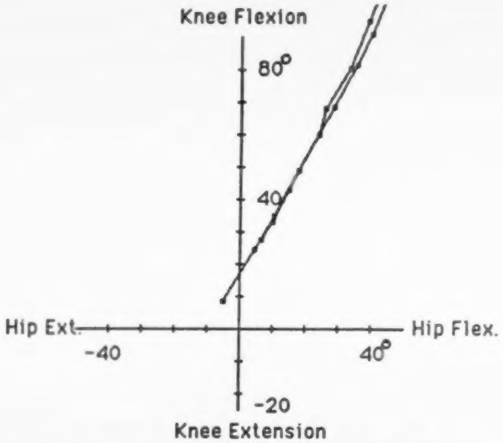

Figure 5: Hip-Knee Angle-Angle Diagram for Marching in Place (Subj. R.C.).The leg travels up and down along approximately the same path. The hip and knee angle relationship is nearly linear with a slope of 1.8.

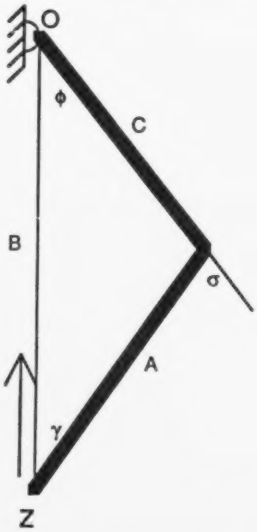

Figure 6: Two-Link Rigid Body Model. The thigh, shank, hip, and ankle are represented by C, A, O, and Z respectively. If the terminal point moves vertically upward, and length A equals length C, the knee angle (ϕ) will be two times the hip angle (σ). If A is greater than C, σ will be less than 2ϕ, and if A is less than C, σ will be greater than 2ϕ.

ACKNOWLEDGEMENT

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COMPARATIVE EVALUATION OF PRESSURE DISTRIBUTION ON FLAT FOAMS AND CONTOURED CUSHIONS

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ABSTRACT

This study was designed to evaluate the pressure distribution at seating interface on flat foam cushions and contoured cushions. The contoured cushions were shaped from the flat foams by following seat contours measured at tissue-cushion interface. The Contour Measuring System (1) and Oxford Pressure Monitor (2) were used with subjects on typical cushions of polyurethane and viscoelastic foams. A simple method was applied to carve flat foams into contoured cushions. It was found that at the buttock-cushion interface the contoured cushions have more uniform pressure distribution and lower peak pressure compared to that of the flat foams. The study will lead to design of contoured cushions for seating.

INTRODUCTION

According to the classical Hertz Contact Theory, the contact area and intensity of pressure over the surface of contact between two general curved surfaces are governed by the curvatures of the two bodies, Young's modulus, E and Poisson's ratio, ν . Ideally, if the contoured shape of the cushion matches the buttocks shape, the peak pressure, pressure gradient, and tissue distortion can be greatly reduced. However, the major difficulty for application of the Hertz Model comes from the complexity of biomaterial behavior of the body tissues and cushions and the over simplified assumptions of the Hertz contact Model. Therefore, experimental methods are used to study the pressure distribution and buttock-cushion contoured interface to provide the clinical application.

METHODS

The instrumented, Adjustable Fitting and Positioning Seat(3) is used to position subjects and measure seat & back contours. One set of Contour Gauges(1), consisting of 64 poteniometers in 16" x 16" surfaces, is used to measure buttock-cushion contoured interface and the other is to measure back contours. The probes of the contour gauges are spaced 2 inches apart from center to center and interfaced with LSI 11/23 computer. Thus, the three dimensional seat and back contours with 64 discrete data points each, can be rapidly recorded and displayed on the 16" x 16" area within 1 minute. The smooth 3-D shape of tissue contour in the entire seating surface is then established by the curve fitting techniques on sampled data of the contact points at the interface.

The method by which the foam is shaped from the measured contour follows several steps. First, the foam is cut along two inch equidistant transverse sections, with exception to the first and last rows, which are sectioned at one inch. Following the polynominal approximation, the foam is marked 1/2 scale of cushion indentation of the contour at every inch along the transverse section. Using a trautman router with a 2" ball rasp head, each section is carved according to the 3-D shape model. The cushion is then glued together using 3M super 74 foam fast adhesive. It is assumed that the glue has no effect on the properties of the foam.

After evaluating pressure distribution on the contoured foam with 1/2 scale contour cutout, it is cut along the glue lines and full scale marking are drawn on the foam. The same procedure is then repeated. The transverse sections are again shaped with the router. The sections are then glued together and the contoured foam is tested for pressure once again.

A 3"-thick polyurethane and viscoelastic foam (TABLE 1) are used in this study.

Table 1

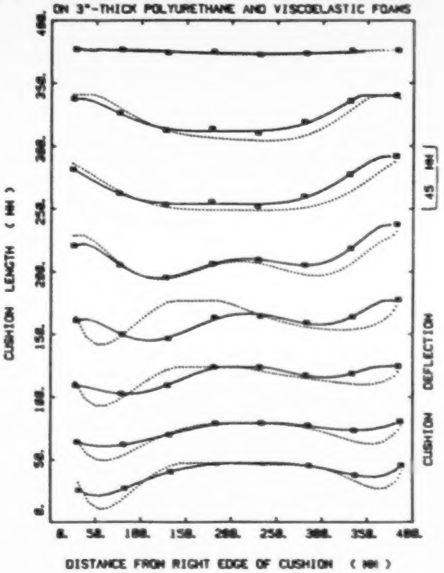
Cushions Used in the Experiment

TYPE	COMPANY	DIMENSION (inches)	COMPOSITION
Polyurethane foam	Everest & Jennings	16 X 16 X 3	low density polyurethane
Viscoelastic foam	Specialty Composites	16 X 16 X 3	medium density urethane

RESULTS

The seat contours of a 23 year male of 170 lbs in weight, having a mild scoliosis due to the unequal leg length, are shown in Figure 1 with the 3"-thick viscoelastic and polyurethane foams in his comfortable sitting position of seat angle = 4^0 and back angle = 98^0 from the horizontal. The dotted curves represent the seat contour for the viscoelastic and the solid curves for the polyurethane foam.

Fig. 1 SEAT CONTOUR SEQUENCE OF A MILD SCOLIOTIC MALE ON 3"-THICK POLYURETHANE AND VISCOELASTIC FOAMS



Using the Oxford Pressure Monitor, the pressure distributions corresponding to the seat contours at the sitting interface are shown in Figures 2 and 3 for the thigh regions and the buttocks.

Fig. 2: Pressure distribution on polyurethane (mmHg)

		25	ANTERIOR		33		
		29			34	THIGH	
		19			33		
		27			28		
L		23			30		R
		30		I.T.	45		
BUTTOCKS	41	37	17	81	52	28	
	30	37	42	84	57	16	
	69	44	75 I.T.	42	45	42	
	32	34	43	41	32	33	
			POSTERIOR				

Fig. 3: Pressure distribution on viscoelastic (mmHg)

		24	ANTERIOR		40		
		24			22		
		27			29		
		22			29		
L		21			31		R
		32			39		
	0	43	66 I.T.	59	62	34	
	65	41	86	77	51	42	
	62	60	56	45	33	39	
	58	49	57	30	33	20	
			POSTERIOR				

Seat contour at the buttocks and pressure distribution corresponding to the contour in the polyurethane foam are similar to these of in the viscoelastic foam; a single region with peak pressure and highest cushion indentation near the mid-line of buttocks is clearly seen. Peaked pressure at the I.T. resulting from both flat foams is higher than 80 mmHg for the subject. The difference of peaked pressures is less than 10 mmHg for both foams. The cushion indentation & pressure of the right thigh are higher than those of the left thigh; for this subject the left leg has 0.5 inch longer in length than that of the right leg.

Following the measured data of contours and polynominal approximation for the curve fitting, the foams are marked 1/2 scale of cushion indentation of the contours and then carved according to the shapes. The Oxford Pressure was repeatedly used to measure the interface pressure for the subject in the contoured foams with 1/2 scale cutout. The pressures are shown in Figures 4 & 5.

Fig. 4: Pressure Distribution on polyurethane foam with 1/2 scale cutout (mmHg)

		21			25		
		24	ANTERIOR		25		
		15			37		
		15			24		
L		31			23		R
		33			32		
	40	41	35	41	26	30	
	50	37	53 I.T.	63	43	39	
	41	34	62	38	42	34	
	33	30	44	27	37	32	
			POSTERIOR				

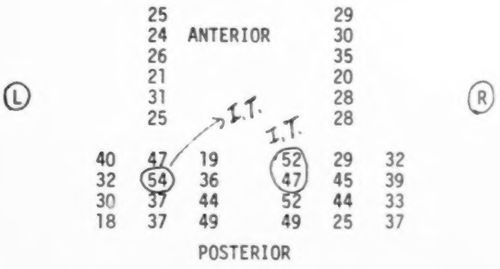
Fig. 5: Pressure Distribution on Viscoelastic foam with 1/2 scale cutout (mmHg)

		21			28		
		21			21		
L		21	ANTERIOR		21		R
		26			15		
		23			25		
		20	I.T.	I.T.	22		
	40	40	32	60	41	41	
	39	70	35	52	48	37	
	33	45	57	42	37	19	
	22	55	20	17	38	29	
			POSTERIOR				

337

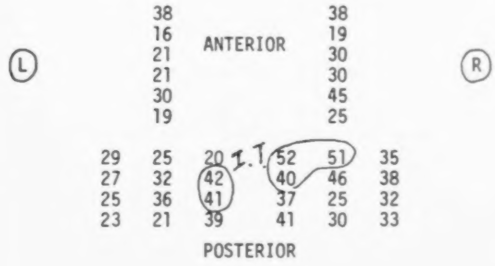
After evaluating pressure distribution on the contoured foams with 1/2 scale contour cutout, full scale contour marking are drawn on the foams and then the foams are carved following the full scale for contour cutout. The pressure distribution on the full scale contoured foams are shown in Figures 6 and 7.

Fig. 6: Pressure Distribution on contoured polyurethane foam with full scale cutout (mmHg)



		25			29		
		24	ANTERIOR		30		
		26			35		
		21			20		
Ⓛ		31			28		Ⓡ
		25			28		
	40	47	19	52	29	32	
	32	54	36	47	45	39	
	30	37	44	52	44	33	
	18	37	49	49	25	37	
			POSTERIOR				

Fig. 7: Pressure Distribution on contoured viscoelastic foam with full scale of contour cutout (mmHg)



		38			38		
		16	ANTERIOR		19		
Ⓛ		21			30		Ⓡ
		21			30		
		30			45		
		19			25		
	29	25	20	52	51	35	
	27	32	42	40	46	38	
	25	36	41	37	25	32	
	23	21	39	41	30	33	
			POSTERIOR				

The data indicate that at the buttocks-cushion interface the contoured foams have more uniform pressure distribution and lower peak pressure compared to that of the flat foams. The data also show more than 20 mmHg reduction in peak pressure by comparing the contoured foams to the flat foams.

DISSCUSSIONS

The results show significant pressure reduction on the buttocks-cushion interface and subjects with sensation commented on increased comfort with the contoured cushions. The next step involves investigation of Biomaterials for foam cushion to optimize the support characteristics of cushion, and improved cutting or shaping methods for designing production of custom cushions.

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COMPUTER-AIDED BACK ANALYSIS SYSTEM

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ABSTRACT

A measurement system for objectively evaluating the muscular deficiencies associated with lower back pain is presented. At the heart of the system is an IBM-PC based myoelectric signal processing device called the Muscle Fatigue Monitor. Other components of the system include: 1) a postural restraint device to reliably stabilize the body, 2) a force acquisition system to monitor trunk loading and 3) specially designed surface electrodes to detect the myoelectric signal. Preliminary studies are described in which a high resolution kinematic digitizing system and a biomechanical model of the lower back are being applied in conjunction with the Back Analysis System to formulate a computer-aided, biomechanical approach to back assessment and treatment.

INTRODUCTION

As many as 75 million Americans now suffer from disabling lower back pain and each year 7 million more people develop this problem (1). Despite the many millions of dollars spent on innumerable treatment for the back, a significant number of patients have chronic, remitting symptoms. Improved methods for screening back disorders and assessing treatment outcome are necessary to control this pervasive problem.

The Back Analysis System was developed in response to a need by clinicians for an objective measure of the muscular component to low back disorders. It is based on a technique that estimates the fatigue rate of contracting muscles by measuring the shift occuring in the frequency spectrum of the surface detected myoelectric signal (2). The dynamic interaction of synergistic back muscles during fatiguing contractions can be represented by "fatigue patterns" created by the frequency shifts occuring in different muscles groups. Differences in these patterns, associated with lower back disorders, represent functional disturbances in back muscles. With this system we can hope to describe imbalances in muscle fatigability and activity levels that may occur either contralaterally or at different spinal levels. Protocols in which the load and posture of the trunk are manipulated may elicit differences in the functioning of back muscles between patients with back disorders and those who never suffer from chronic back pain. The ability to quantify these, and possibly other disorders associated with low back pain may serve as a basis for prescribing treatment programs and measuring their effectiveness by follow-up assessment. At the present time, there are no well documented, objective treatment outcome measures for low back pain, particularly for non-surgical approaches to back pain management. As a result, a confusing proliferation of treatment approaches to this malady continues to develop without a well demonstrated scientific basis or an adequate objective measure of the treatment effect.

In this paper we describe the instrumentation that comprises the system and briefly present several related studies that are presently being pursued by us to test the viability of the system for assessing and treating low back pain.

SYSTEM DESCRIPTION

IBM-PC Muscle Fatigue Monitor

At the heart of the Back Analysis System is an IBM-PC based signal processing device called the Muscle Fatigue Monitor (MFM). This device calculates the median frequency and the RMS of the EMG signal in real-time using analog circuitry similar to that described in a previous publication (3). As presently configured, it can accommodate up to 10 EMG channels and 2 force channels of input. Changes in the median frequency during a sustained muscle contraction are associated with the muscle fatigue process. The electronic circuitry used to measure muscle fatigue was designed to be compatible with the standard card slots of the IBM-PC series computers. It therefore has a wide range of color graphic and data formulation capabilities. Assembly code has been developed to implement data acquisition and storage, error processing, and real-time plotting.

Postural Restraint Device

A clinical restraint device that reliably stabilizes the pelvis and lower limbs during standing was designed and constructed to assure that the sustained, isometric muscle activity observed is actually associated with the flexion, and rotary torques being monitored. The final design incorporated many of the features of a similar prototype device that was described previously (4) and was used primarily for laboratory-based studies. The modifications to this original design were primarily to reduce its size, make it free-standing and simplify the number of adjustments that would need to be made for testing a subject. Considerable effort was was made to design the restraint apparatus so that the individual's pelvis could be immobilized at a desired pelvic tilt without discomfort. By constructing the device out of a perforated, modular tubing system, the apparatus can be easily tailored to accomodate any size individual comfortably. Additional components can be easily attached to the central support column of the device to allow for different degrees of trunk, hip and knee flexion and to provide partial weight bearing at the patellar tendons and buttocks if desired.

Force acquisition device

The torque generated during an isometric contraction of the back muscles is measured with a harness positioned across the desired region of the back. Two sensitive load cells attached to this harness and the postural restraint device measure the forces produced as the back muscles contract. Differences in the force computed from the two transducers can provide a measure of the degree to which a "pull" is symmetrical or includes a rotary component to the resulting torque. A maximal voluntary contraction (MVC) acquisition system was also designed into the device via a processing card that plugs into one of the expansion slots of the IBM-PC. With software support, this device calculates the MVC by averaging force values over an adjustable window. The MVC force value is stored and can be used to set a visual display unit to the desired percentage of the MVC. The feedback display is often necessary to help the subject maintain a constant level of contractile force. The system is easily adaptable to programming a full range of test contractions at the appropriate duty cycles for a desired set of test contractions. It is therefore possible to have the IBM-PC essentially run an entire test sequence.

Surface electrode detection and conditioning

The system, as presently configured, consists of ten surface electrodes with appropriate signal conditioning instrumentation. After much redesigning and testing, we have developed an electrode unit that meets the rigid demands of recording ME signals from back muscles during forceful contractions. The electrodes are able to provide consistently high signal to noise with minimal motion artifact. Their signal conditioning circuitry is similar to that described by De Luca and Gilmore (5). They have been modified to be compliant and therefore conform to the muscle contour. They have a low profile (less than 1/16 in.), are extremely lightweight, and are self-adhering to the skin. The electrodes are connected to a compact preamplifier with 10 channels that is worn about the subject's waist and is connected by a ribbon cable to the dedicated IBM-PC for further conditioning and processing.

DISCUSSION

Several studies are underway using the Back Analysis System that will collectively determine the viability of this system as a clinical tool. A protocol is being implemented to establish the repeatability of the fatigue measures on the same and different days. Control subjects and chronic back patients are being tested separately and are required to produce three sustained contractions at 80%MVC for 30 s. each. The subjects are then being retested using the same protocol on a different day. Another body of work is being conducted to investigate the effects of varying the length of the recovery period on the fatigue parameters. This study will also involve a comparison between controls and chronic back patients. The results will have not only methodological implications, but also provide information about the physiological adaptations to muscle that may be associated with chronic back pain.

A third research effort in this series of studies is to compile a large data base of EMG test results in which the effects of different load levels and body postures will be compared for back patients and normal controls. Highly accurate measurements of body position will be provided by the WATRACK motion analysis system. This system combines the proven performance of WATSMART hardware to measure the spatial position of LED's attached to the body with the TRACK software for data analysis. The TRACK software utilizes a unique method of mounting the LED's on rigid segments and attaching the segments to the links whose motion or position is under study. Such a technique is able to extract six degrees of freedom of each of the links with a spatial resolution of 1 mm. The kinematic information will be combined with an anotomical data base that includes cross-sectional area measures of trunk muscles from the CAT scans of subjects. This information will be necessary to test a biomechanical model of the lower back that is presently under development. This model, when optimized by the fatigue test results, can be used to calculate the load distribution among the different muscles at a particular level. The biomechanical model could therefore be a tool which could be utilized in both the diagnostic phase to identify individual muscle dysfunction and in the prescription phase to suggest isometric exercises intended to selectively activate or relieve individual muscles. This approach, which we describe as "Computer-Aided Physical Therapy", is summarized in Figure 1.

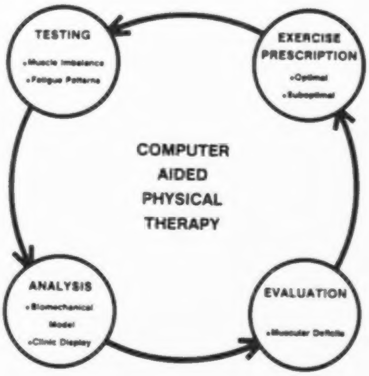

Figure 1

ACKNOWLEDGEMENT

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ELECTRIC GONIOMETER DESIGNED FOR MEASURING HIP FLEXION ANGLE IN CHILDREN WITH CEREBRAL PALSY IN THE SEATING POSITION

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ABSTRACT

The position of the hip joint during sitting is crucial to the overall effectivenesss of a seating system for children with cerebral palsy. In order to evaluate the effect of the hip flexion position on specific variables in children with cerebral palsy, direct and objective measurement of the hip joint must be made. An electric goinometer designed to accomplish this goal cosists of three main parts: a proximal arm, a potentiometer, and a distal arm. The design of the proximal and distal arms ensures that only relative positions of the thigh and pelvis are registered as hip flexion angles. Movements of the low-back do not affect the goniometer and are excluded from hip flexion measurements. By providing information on the position of the hip joint, the device has been used to position adaptive seating components so that desired hip position and placement is achieved.

INTRODUCTION

The angle between the seat surface and backrest of a seating system and the angle of hip flexion has been shown to be different for children with cerebral palsy.[1] Therefore, hip flexion angle should not be stated as the angle between the seat and backrest surfaces or the angle of inclination of the backrest.

The position of the hip joint in seating is crucial to the overall effectiveness of the seating system for these children. Whether the hip is serving as an independent variable in a research study or is being positioned during actual fitting of an adaptive seating device, it is important that changes in the position of the hip joint itself be accurately determined. An electric goniometer described here was designed to monitor and measure changes in hip flexion angle while positioning children with cerebral palsy.

COMPONENTS AND OPERATION

The goniometer shown in the Figure is designed for use while the child is seated. It consists of three main parts: a proximal arm, a potentiometer, and a distal arm. The proximal arm is made of Orthoplast and is preshaped to fit the general contour of the lateral aspect of the pelvis. The anterior and posterior aspects of the proximal arm extend to the anterior and posterior aspects of the pelvis, respectively. Each aspect contains a rubber cup that is positioned on the skin over the anterior-superior iliac spine and the posterior-superior iliac spine.

The center of the goniometer contains a potentiometer, or variable resistor. A constant-voltage electrical current is supplied to the potentiometer through a cable. The resistance to this current depends on the relative position of each arm of the goniometer and, consequently, on the range of motion at the hip. The output voltage from the potentiometer varies linearly with the ROM at the hip, and voltage level is converted by computer software into degrees of movement. The ROM is displayed on a video monitor every second. The goniometer has an operational ROM of 40 to 285 degrees.

The distal arm is made of low-density polyethylene. It also contains two rubber cups--a proximal cup, positioned on the skin over the greater trochanger, and a distal cup, positioned on the skin over the lateral epicondyle.

The medial surface of the rubber cups contains double-sided adhesive tape that secures the arms of the goniomter to their respective bony prominences. A pair of Velcro straps further secure the arms to the patient's body (Figure, insert). The use of cups and straps ensures that movements of the pelvis or thigh in the sagittal plane are accompanied by a corresponding movement of the arms of the goniometer. Because the proximal arm is located on the pelvis, only true hip flexion angle is recorded; all trunk movements are excluded.

The materials with which both arms are made allow them to be twisted and bent laterally (but not anteriorly or posteriorly). This property of the goniometer ensures that lateral or medial rotation and adduction or abduction of the hip are accommodated but do not affect the measurement of hip flexion. This construction also ensures that the goniometer is not displaced from the hip during testing and that the axis of rotation of the goniometer is at the axis of rotation of the hip joint. The length of both arms of the goniometer and the position of the cups on the arms are adjustable for different body sizes.

VALIDITY AND RELIABILITY

The validity of the electric goniometer was evaluated by comparing hip angle measurements obtained from it with measurements obtained from a manual goniometer. For the four individuals (2 normal and 2 with cerebral palsy) used for this evaluation, the hip was placed in different positions, and readings were obtained from both goniometers. Manual tests were performed by the same evaluator. All measurements were made to the nearest degree. The maximum difference between readings obtained from both goniometers was less than 3°. Based on these results, the electric gonimeter was considered a valid device for measuring hip flexion angle.

The reliability of the electric goniometer was tested by performing test-retest measurements at predetermined positions while disconnected from the subject. It was found to be 100% reliable.

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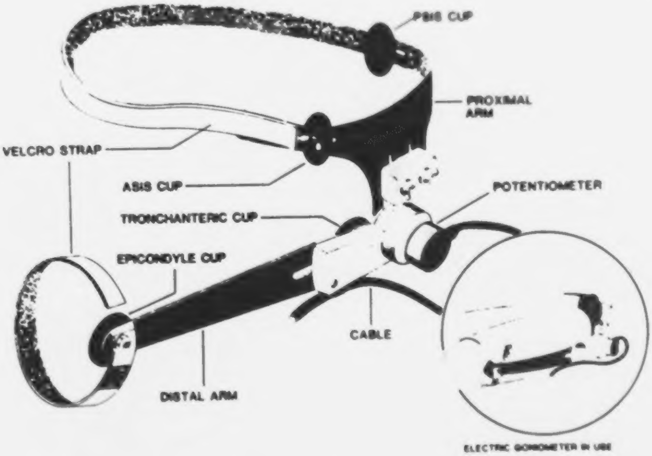
PSIS CUP
PROXIMAL ARM
VELCRO STRAP
ASIS CUP
POTENTIOMETER
TRONCHANTERIC CUP
EPICONDYLE CUP
CABLE
DISTAL ARM
ELECTRIC GONIOMETER IN USE

Fig. 1. Lateral view of the electric goniometer.

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DEVELOPMENT OF A WHEELCHAIR AEROBIC FITNESS TRAINER

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ABSTRACT

A new modality specific exercise device for aerobic conditioning, cardiorespiratory fitness testing and the rehabilitation of persons who are restricted to manual wheelchair locomotion is described. The device is called a Wheelchair Aerobic Fitness Trainer (WAFT). Preliminary tests of the WAFT have shown that the WAFT can: a) be used to simulate the energy requirements of low velocity wheelchair locomotion, b) provide workload increments appropriate for fitness testing of the apparently healthy, c) produce peak exercise performances similar to those obtained by arm cranking, and d) provide reliable test results. The WAFT thus resolves many problems associated with other wheelchair exercise devices.

INTRODUCTION AND DESCRIPTION OF DEVICE

Equipment related exercise (e.g., bicycles, treadmills weight machines and free weights) attracted 8.1 million new participants in 1985 and was rated the fastest growing sport in the United States by the National Sporting Goods Association. However, little attention has been given to the development and improvement of personal exercise equipment for individuals who are restricted to wheelchairs. In response to this need, we have constructed and tested a prototype device designed for the evaluation, rehabilitation, and development of cardiorespiratory fitness in persons whose primary mode of mobility is the manually operated wheelchair. We call this device a Wheelchair Aerobic Fitness Trainer (WAFT). Careful attention to cost, user independence, and rehabilitation applications was paramount in the design of the WAFT.

The WAFT is a modality specific exercise device designed to: 1) accommodate the user's own wheelchair; 2) provide an inexpensive, yet valid and reliable device for graded exercise stress testing/rehabilitation and/or aerobic training that is operational in a relatively small space; 3) provide a form of exercise that requires the use of the motor patterns that are specific to wheelchair propulsion, i.e., satisfies the tenets of training specificity; 4) provide a safe, durable and easy to operate personal exercise machine for aerobic fitness training; and 5) provide the recreational and competitive athlete with accessibility to a training device that can be located at home, at work, or at a health club/fitness center. While aerobic exercise devices for upper body training/testing (i.e., arm crank ergometer, wheelchair rollers, some treadmills) are currently available, none satisfy all of these criteria.

A unique user controlled system for tilting the WAFT platform during wheelchair loading and unloading allows a person to back his/her personal wheelchair into position for exercise. The WAFT features high inertial loading so that the wheelchair wheels continue to turn during the recovery phase of the propulsion cycle. Each wheel of the wheelchair turns on three rollers that are 16 cm long and 10 cm in diameter. The translational inertia that occurs during normal wheelchair operation has been replicated by placing balanced weights inside each of the six rollers. User-controlled variable resistance is provided to each wheel by independent magnetic braking assemblies that also have inertial flywheels. These commercially available variable resistance devices are mounted on the WAFT frame and held against the wheelchair wheels by a calibrated adjustable spring. This component to the WAFT allows the user the freedom to adjust the workload to meet the requirements of the graded exercise testing protocol or exercise program. The resistance and speed of each wheel may be manipulated independently depending on the user's objectives and physical abilities. Electronic tachometers give the user continuous feedback regarding the speed of both wheelchair wheels and provide input to electronics that determine relative velocity and projected heading. Initial experiments have begun wherein the WAFT is coupled to the game port of a computer for the purpose of simulating wheelchair locomotion where the user negotiates the twists and turns of a labyrinth (an activity intended for use during the preliminary phases of wheelchair mobility training); and making it possible to play motivating computer games during rehabilitation and aerobic exercise training.

METHODS

Five non-disabled males and one male with paraplegia gave their written consent to participate in the preliminary tests of the WAFT. Physical characteristics of the non-disabled subjects were: age 24.2 (±3.9 SD) years; height 178.69 cm (± 9.96), weight 72.54 kg (±12.18). The individual with T10 complete paraplegia was 21 years old, 185.42 cm tall, and weighed 72.54 kg. All subjects satisfied the American College of Sports Medicine (ACSM, 1986) criteria for the graded exercise testing of apparently healthy individuals.

Arm cranking: Subjects completed one maximal arm cranking (AC) exercise test a on a Quinton Imaging/Table electrically braked ergometer that was modified for this purpose. The AC protocol employed discontinuous, progressive resistance exercise. Exercise stages were 3 minutes in duration with a four minute rest interval between stages. Subjects rested quietly for 5 minutes prior to beginning the exercise test. The height of the ergometer was adjusted so that the midpoint of the chainwheel was at shoulder level. During cranking the subject's arms, at point of maximal reach, were extended at right angles to the body with a slight bend in the elbow. The initial workload was set at 200 Kpm/min with increase of 150 Kpm for subsequent stages. Cranking rate was maintained at 60 rpm.

WAFT: Subjects also completed one maximal WAFT discontinuous graded exercise test. Several subjects completed two tests on the WAFT. Changes in exercise stress were accomplished by increasing the speed at which the wheelchair wheels were pushed and by increases in the settings on the magnetic resistance devices. The available resistance settings are: very very low (VVL), very low (VL), low (L), moderate (M), high (H), very high (VH), and very very high (VVH). However, of the 7 possible resistance settings only four VVL, L, H, and VVH were used in the discontinuous test protocol. Subjects rested quietly in their chair for 5 minutes prior to beginning the test. Wheelchair wheel were maintained at an inflation pressure of 50 psi. The subjects began the test by completing a 3 minute warm-up without the resistance assemblies engaged, i.e. freewheeling. After the warm-up the subjects began at 2mph and VVL resistance setting. If the subject's heart rate during the last 15 seconds of the third minute of exercise was less than 65% of his predicted maximal heart rate the velocity for the next stage was increased by 1mph with the resistance setting remaining at VVL. Predicted maximal heart rate was determined by subtracting the subject's age from 220. This procedure was continued until the subject's heart rate, measured during the last 15 sec. of a stage, was greater than 65% of his predicted maximal heart rate. When this condition was met the subject would maintain the same velocity for subsequent stages with increases in workload being accomplished by increasing the resistance (see Figure 1). In both the AC and WAFT maximal graded exercise tests, subjects continued exercise until they: 1) were unable to maintain the designated work intensity, 2) reached volitional fatigue or 3) manifested significant clinical signs or symptoms at any workload.

Heart rate was derived from the V5 lead of an electrocardiogram (ECG) using a Quinton Status 1000 ETT System. Blood pressure was determined during the first 30 seconds immediately following an exercise stage using a Critikon Dinamap Vital Signs Monitor Model 845XT. Oxygen uptake (VO2, STPD) and pulmonary ventilation (VE, BTPS) were determined by open circuit spirometry. Subjects breathed through a two-way Rudolph valve held in place by an adjustable headgear assembly. Expired gas was collected in a 120 liter Tissot. Changes in Tissot volume were sensed by a potentiometer and the output recorded on a Grass Model 7 polygraph. Expired gases were then analyzed for O2 and CO2 concentrations by a Beckman OM-11 polarographic O2 sensor and infrared Beckman LB-1 Carbon Dioxide Analyzer with a Beckman Linearizer. The analyzers were calibrated before, during, and after exercise tests with room air and reference gases of known concentrations. Rating of perceived exertion (RPE) were obtained by using Borg's category scale (Borg, 1982). All measurements, with the exception of blood pressure, were taken during the last minute of each stage of the exercise tests. Ambient temperature in the laboratory was maintained at 25.5° C. Prior to testing, subjects attended an orientation session to familiarize them with the operation of the instrumentation, and opportunity to practice using the AC, and WAFT.

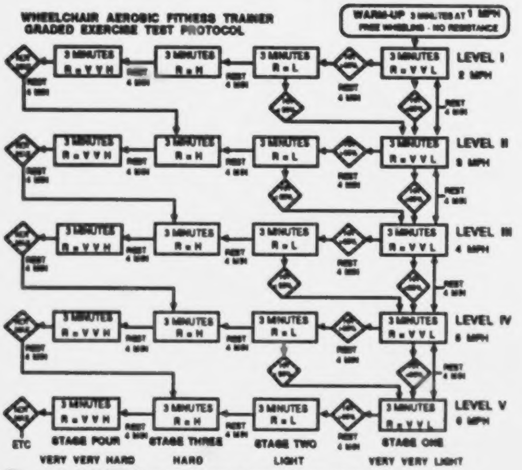

Figure 1. WAFT discontinuous graded exercise test.

RESULTS AND DISCUSSION

In these initial experiments it was important to determine if a person exercising on the WAFT would experience physiological stresses very similar to actual wheelchair locomotion. Glaser and Collins (1981) have reported that wheelchair locomotion at 3 km/h on a tiled surface requires an oxygen uptake of 0.60 l/min and 0.84 l/min for travel at the same velocity on a low pile carpet. Oxygen uptake was 0.61 l/ min during freewheeling on the WAFT at 1.61 km/h. Pushing at 3.22 km/hr with magnetic resistance assemblies engaged and set at VVL required an oxygen uptake of 0.87 l/min. It would appear from these findings that simulated wheelchair locomotion on the WAFT requires an energy expenditure similar to that encountered during normal low velocity wheelchair travel. It is expected that a recent upgrading of the WAFT roller bearings will further reduce these measures.

General principles of graded exercise testing, no matter what the mode of testing, hold that: a) the exercise test would begin at a level of intensity well below the anticipated limitation or maximal capacity of the person tested, b) exercise intensity should be increased gradually in stages, with observations completed at each stage and c) the increases in stages may be as large as 2 metabolic equivalents (METs) or more in healthy individuals or as small as 1/2 MET in those with cardiovascular and pulmonary disease (ACSM, 1986). The net MET for each stage in the WAFT discontinuous graded exercise test and the resulting increases in METs with increasing stages are presented in Table 1. Consistent increases in metabolic demand were seen with increasing stages. At lower stages, the changes in METs fall within guidelines for graded exercise testing of healthy individuals. It is important to note that the MET changes reported here result from speed increases of 1 mph and, when called for, 2 step increases in resistance settings. Therefore, smaller changes in speed and resistance (i.e., 0.5 mph and single step increases in resistance) are possible and will likely result in less than 1MET increases in the initial stages of the testing protocol. This modification has been adopted in new continuous graded exercise tests for the WAFT. If the smaller step changes produce the expected results then the testing protocol will be satisfactory for testing wheelchair restricted persons with cardiovascular and pulmonary disease.

The peak values for heart rate, oxygen uptake, minute ventilation for subjects who completed both WAFT and AC discontinuous graded exercise tests are presented in Table 2. The large differences in minute ventilation between AC and WAFT in the non-disabled were due to the exercise tolerance of two upper body trained, high fit subjects. During the WAFT test these subjects used a much greater percentage of their upper torso to push the wheelchair wheels than they did turning the cranks during AC. In these subjects the WAFT test-retest reliability coefficient for heart rate and oxygen uptake were r=0.96 and r=1.00.

Resistance Setting	Velocity km/h (mph)	METS	Resistance Setting	Velocity km/h (mph)	METS	Difference
Warm-up	1.61 (1)	2.46	VVL	3.22 (2)	3.49	1.03
VVL	3.22 (2)	3.49	VVL	4.83 (3)	5.10	1.61
VVL	4.83 (3)	5.10	VVL	6.44 (4)	7.11	2.01
VVL	6.44 (4)	7.11	L	6.44 (4)	9.23	2.12
L	6.44 (4)	9.23	H	6.44 (4)	12.34	3.11
H	6.44 (4)	12.34	VVH	6.44 (4)	13.27	0.93

Table 1. Changes in metabolic equivalents (METS) with increases in exertion levels during the WAFT discontinuous test.

Subjects Test mode	Heart rate (bpm)	VO2 (l/min, STPD)	VE (l/min, BTPS)
Non-disabled (n = 3)			
WAFT	178 (16.65)	2.63 (0.66)	143.04 (16.54)
Arm crank	175 (12.50)	2.78 (0.48)	118.42 (6.25)
Disabled (n = 1)			
WAFT	187	2.07	81.35
Arm crank	199	2.19	87.37

Table 2. Means (standard deviations) of the peak values for heart rate, oxygen uptake, minute ventilation for subjects completing both WAFT and AC discontinuous exercise tests.

At any given percentage of peak oxygen uptake RPE was slightly higher for AC than for exercise on the WAFT. It is interesting to note that this relationship between RPE and percent of oxygen uptake is very similar to the relationship between heart rate and percentage of peak oxygen uptake. Subjects were able to accurately perceive the magnitude of their effort with regardless of the work mode. The correlation between heart rate and RPE was greater for the WAFT (r=0.95) than for AC (r=0.87). Between RPE and percent of oxygen uptake, the WAFT was also greater (r=0.96) than AC (r=0.90). This is somewhat surprising considering that most of the subjects were unfamiliar and unskilled in wheelchair locomotion. It is possible that the number and magnitude of perceptual cues associated with wheelchair locomotion provide a more complete psychophysiological picture for determining RPE than are available during AC.

We believe that we are not building just another exercise device for distribution to the wheelchair-bound consumer. We are obtaining and providing information, from objective observations, that support the operation and varied applications of the WAFT in improving the aerobic fitness, and hence modifying the cardiovascular disease risk profile of these individuals.

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TECHNOLOGY FOR CLINICIANS: MOBILE MICROCOMPUTER FOR TRAINING PRESSURE SORE PREVENTIVE BEHAVIOR

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ABSTRACT

A portable, low-cost computer (the TLC, or Timer-Logger-Communicator) has been developed to improve training in wheelchair pressure-relief lift-offs and leans. Proper performance of these self-care behaviors prevents ischial pressure sores among persons with spinal cord injury. The TLC attaches to the wheelchair and records lift-off behavior continually throughout the day. The TLC data reveal the extent to which pressure relief behaviors occur. The data also show the outcomes of teaching interventions, so that the effectiveness of teaching can be assessed and, when appropriate, interventions altered.

INTRODUCTION

Many persons with spinal cord injury (SCI) are at risk to develop severe ischial pressure sores. These pressure sores are thought to occur as a consequence of frequent and prolonged periods of sitting in a wheelchair without movement. The primary etiologic factor in the development of these sores is hypothesized to be ischemia resulting from pressures exceeding capillary pressure for extended times. (See also (1), (2), and (3) for more extensive discussions and bibliographies.) When seated, persons with intact sensation eventually become uncomfortable and shift their weight. Persons who have sensory loss associated with SCI don't become uncomfortable and frequently sit in one position for extended periods of time. Therefore, planned pressure relief movements must be performed to prevent tissue breakdown. A goal of the rehabilitation program for persons with SCI is to teach them to relieve pressure once every 20 to 30 min. for the rest of their lives.

BACKGROUND

Evaluating the effectiveness of teaching is essential to training persons to routinely and consistently perform pressure reliefs. An objective method of measuring the routine performance of these behaviors, so that training procedures could be evaluated, and if necessary, changed, was the major objective of this project.

In addition, if the device could alert the patient and/or staff to periods of excessive sitting without a sufficient pressure relief, it might lower the patient's risk of developing a pressure sore during training. Previous work (4) has indicated that while some people seem to respond well to an intermittent alarm over short periods of time, such a device may not work for others. The data collection capability allows the staff to determine for whom such interventions are effective.

Finally, the device must reliably detect both complete lift-offs (which most paraplegics perform) and lateral leans (which are performed by many quadriplegics) with all cushions and seating arrangements.

The Timer-Logger-Communicator (TLC) has been developed to meet these needs. The TLC's continuously records the patient's pressure-relief behavior, enabling the clinical staff to evaluate the effects of teaching interventions. Sharing the data with the patient provides an additional teaching intervention. The TLC also can signal the patient during training. It can be programed so than one signal registers a good pressure relief, while another acts as a reminder.

With the TLC's signaling capability, the wheelchair effectively becomes a learning environment. The type and timing of signals can be tailored to the individual, based on his or her performance. Experiments to evaluate the effectiveness of a variety of signalling routines are planned.

METHODS

Subjects

Over 30 patients with spinal cord injury (SCI), paralysis, and sensation loss have been run with one or more versions of the system (3, 4, 5).

Apparatus

Figure 1 is a representational diagram of the entire TLC system. The TLC is depicted in the upper left; it is enclosed in a small (7"X4"X2") plastic box. It can be attached to the frame of a wheelchair under the seat, where it does not interfere with normal use or folding of the chair. In the box is a single-board microcomputer based on the Hitachi HD6803RP CMOS microprocessor, with an 8K ROM, 32K of RAM, batteries, and connectors. Wires lead from the box to switches on the seat which detect sitting pressure. Outputs (labelled "stimuli" in the drawing) allow audible or visual signalling of the patient or staff when needed. The portable part of the TLC system consists of these three parts; they respectively control the process, sense movement, and provide signals.

To keep the size, cost, complexity, and weight of the system down, the TLC has no keyboard, display screen, or mass storage device. These are provided by an Apple IIe, IIc or IIgs which acts as a host. The host must have a minimum of 64K of RAM and at least one disk drive. It is desirable to have a printer and/or plotter connected to the host computer.

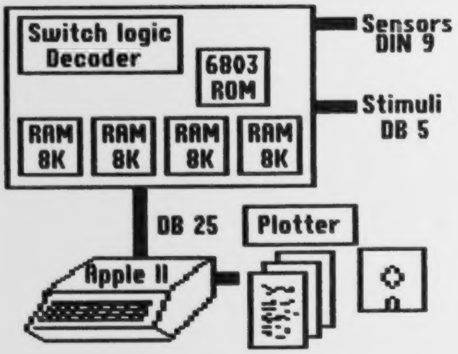


Fig. 1. Diagram of TLC system.

Operation

Before data collection begins, the TLC and host are connected by a cable. This can be done while the TLC is mounted on the wheelchair. Commands for the upcoming session are entered into the TLC through the host. The TLC is then disconnected from the host and connected to the seat sensors. Powered by its battery, the TLC collects data independently. The TLC is periodically reconnected to the host for data retrieval. The data are permanently stored by the host on hard or floppy disks. Data analysis and display are done on the Apple computer screen, printer, and/or plotter. Over 100 TLCs can be supported by one Apple.

Operating life

Data collection is limited by battery size. Approximately 4 days of data can be collected when the TLC is equipped with one 1.2 amp hr. battery. Longer intervals can be recorded by doubling the internal battery or attaching an external battery pack. To prolong battery life, CMOS devices are used and the system clock speed is set at .461 MHz. In addition, the microprocessor's low power consumption "sleep mode" is enabled approximately 1 minute after all switches are open. A lithium cell is used to back-up the RAM if the system voltage drops below 3 v. This prevents the loss of collected data should the main batteries run down.

RESULTS

Sensors

One of the major milestones in the development of the TLC was the design and construction of a reliable mechanism for sensing lift-offs and leans. Design objectives included safety, low cost, reliability, sensitivity (detection of right and left leans as well as full lift-offs), clinical acceptability, specificity, durability, non-invasiveness, convenience, small size, and low weight. In addition, the pressure sensors had to: be compatible with small scale manual assembly, be of minimum height (to avoid irregular pressure on the patient), have a quiescent current drain of less than 1ma, and be insensitive to patient position, moisture, excessive force, and chair vibration. Other requirements included the ability to function with all commercially available cushions, with patients of various weights, and with all chair sizes. The present sensor system is shown in Figures 2 and 3.

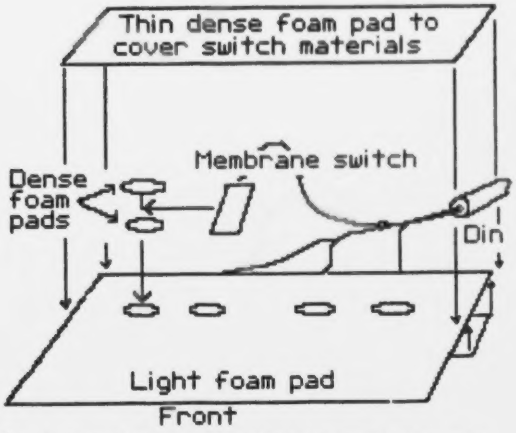


Fig. 2. View of sensor system showing placement of membrane switches. The "thin dense foam" is Plastizote, while the "light foam" is a 1/2" generic soft seat cushion foam that fits the wheelchair sling.

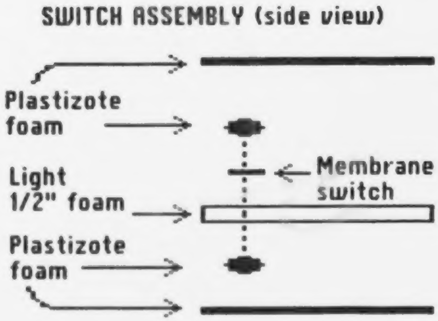


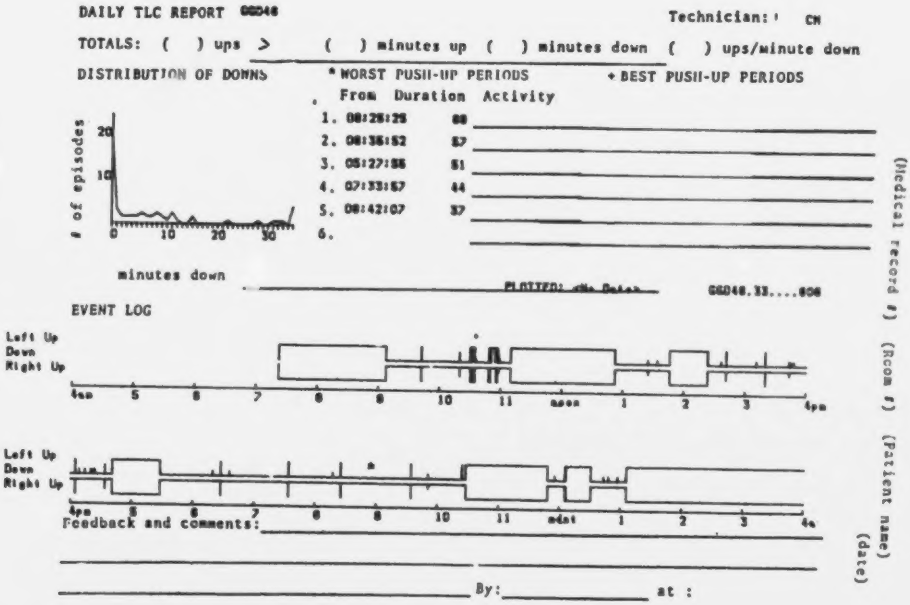
Fig. 3. Side view showing construction of switches. A circular hole is punched in the light foam for the small Plastizote pads. These enclose the membrane switch and hold it within the light foam, and in turn are held by the larger Plastizote sheets. In use, the assembly is encased in a denim pillowcase with Velcro tabs that position it securely on the seat sling.

Data Display

The data collected with the TLC can be displayed in several formats. Lists, counts, and frequencies (count per minute) of events and event sequences can be examined and manipulated. These events can also be displayed and printed as event records and cumulative records. The Daily TLC Report (Fig. 4) was designed to give the patient and staff clear, simple, objective, and detailed feedback about the performance of this critical self-care behavior. In discussion the Daily TLC Report with the patient, staff can focus on positive performances, and also note times of day when performance should be improved. Since the display is time-based, the patient and staff can isolate activities associated with the best and worst performances, and design strategies to make pressure reliefs more consistent.

DISCUSSION

Patients differ widely in behavioral characteristics. If a teaching program is to produce maximum sustained cost-effective behavior change, it must accomodate the variety of persons likely to be seen. For example, previous work (4) has shown the limitations of simple alarm systems designed to remind people to do pressure reliefs. While they work for some people, they do not work for others. When one also considers that a hallmark of rehabilitation is that the patient is changed by the process, the potential for continual change of the teaching program is desirable. Such change may be guided by data on relevant patient performance. Obviously, the quality of the data and cost of collection are critical factors. To support timely, accurate inference about the program, data must be available quickly and care must be taken to rule out all possible threats to the correctness of inference. The TLC system provides data and decision support tools with which a successful, documented, individual rehabilitation program to prevent ischial pressure sores can be built.



DAILY TLC REPORT GGD48 Technician: CN

TOTALS: ( ) ups > ( ) minutes up ( ) minutes down ( ) ups/minute down

DISTRIBUTION OF DOWNS * WORST PUSH-UP PERIODS + BEST PUSH-UP PERIODS

	From	Duration	Activity
1.	08:25:25	88	
2.	08:36:52	57	
3.	05:27:55	51	
4.	07:33:57	44	
5.	08:42:07	37	
6.			

PLOTTED: <No Date> GGD48.33....808

EVENT LOG

Feedback and comments:

By: at :

(Medical record #) (Room #) (Patient name) (date)

Fig. 4. Daily TLC Report showing status of lifts and leans for 24 hrs. Data are plotted on a photocopied form containing standard text. Tracings in the center show the pattern of activity; on this day the patient was active in the morning but showed poorer performance during the evening. A full excursion of the pen shows a pressure-relief of at least 5 sec.; smaller duration movements are proportionally shorter. Times and durations of the worst periods are given in the tabular area, along with a space for the patient to note the activities occurring at these times.

ACKNOWLEDGEMENTS

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THE EFFECT OF LENGTH ON THE AXIAL FORCE APPLIED TO WALKING CANES

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ABSTRACT

An adjustable cane was instrumented to record the axial force applied to it. For four normal subjects with one knee immobilized, the cane length was adjusted to vary their elbow flexion angle. The data show two ranges of elbow flexion which result in peak loads applied to the cane.

INTRODUCTION

The ideal cane is of correct length, handgrip and design to promote optimum stability of assisted ambulation with minimum effort. Physical therapists, however, have no objective data to guide them in the selection and prescription of canes. This type of data is necessary for valid selection and adjustment of canes, and can be used to train individuals in the use of canes or assess improvement in their performance (1,2).

The purpose of this study is to quantitate the effect of several length adjustment criteria on characteristics of assisted gait for patients with a unilateral lower extremity disability. Proper cane length should enhance the efficacy and stability of assisted gait, and increase patient comfort and compliance in the use of the prescribed cane. With greater stability, the risk of falling and causing injury is significantly reduced.

Two methods for cane length adjustment are primarily addressed by the literature. One method equates the length of the cane to the distance from an anatomical landmark, such as the greater trochanter or the styloid of the ulna, to a point six inches forward and lateral to the foot. The second method determines cane length by the amount of initial elbow flexion, measured during stance, while holding the cane tip to the above described point on the floor.

It is commonly agreed that elbow flexion is required for optimum support and minimum fatigue during cane-assisted ambulation, however, published recommendations for elbow position vary from zero to forty degrees of flexion. Clinically, canes which are too long cause fast fatigue of the elbow extensors, place the shoulder in elevation, and generate extreme compressive loads in the wrist because of the excessive ulnar deviation.

Short canes require too much elbow extension to allow adequate braking or propulsion by the cane. Patients are forced to compensate with shoulder depression, excessive hip flexion, and tilting of the torso. All of these factors reduce stability (3).

METHODS

An adjustable aluminum crook handled cane was instrumented with strain gage bridges for assessment of the resultant axial force at the tip. The calibration curve for this circuit is shown in Figure 1, and has a correlation coefficient of 0.89. The standard error of the estimate is 9.58 mV. The cane was calibrated in tension; the results are extrapolated for compression.

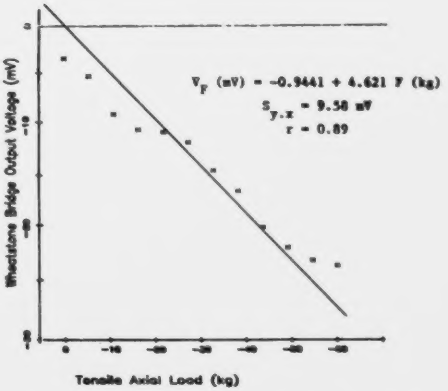

Figure 1: Calibration data for the strain gage bridge mounted to the cane for measurement of axial load.

The cane used was modified to allow length adjustment in half-inch increments. For each trial, the cane length was adjusted to vary the subject's elbow flexion angle within the range of 0 to 50 degrees. The measurement of elbow flexion was performed with the subject standing still, with the cane tip six inches forward and lateral to the foot, as described above. These initial angle values are used as the independent variable for the axial load data.

Peak axial loads transmitted through the cane were recorded from the strain gage bridges and averaged over four strides. The subjects for this experiment were two females and two males who mimicked a lower extremity disability by wearing a DePuy leg immobilizer to limit the range of motion of the left knee. The subjects used the cane in the hand contralateral to the "affected" limb, which was their dominant hand in all cases.

RESULTS

The peak axial loads for four subjects with the left knee immobilized were examined, and are expressed as a percentage of body weight in Figure 2. The males applied consistently higher percentage of their body weight loads to the cane than did the females; in fact, much higher loads than are recommended for cane use. It is strongly advised that no more than 25% of the body weight be exerted on canes, because of the instability associated with their having only one point of contact with the body for support (4).

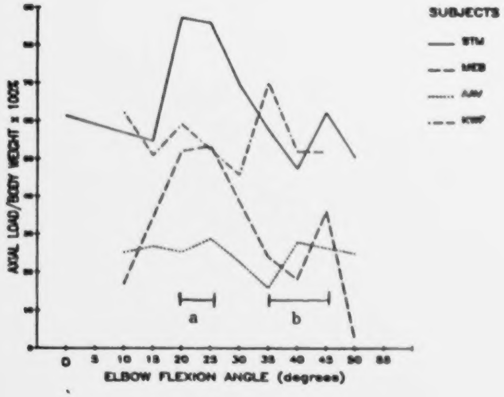

Figure 2: Axial load exerted on the cane as a function of initial elbow flexion angle. These data are normalized to the subjects' body weight. The first maxima observed (a) fall within the range of 20-27 degrees of elbow flexion, while the second peaks (b) occur between 36-47 degrees of flexion.

All subjects exerted larger axial loads on the cane within the twenty to thirty degree range of initial elbow flexion angles. Interestingly, this is the most commonly recommended range for proper cane use. A second maximum was consistently observed for all subjects tested, occurring near the upper end of the range of initial elbow flexion angles, between 36 and 47 degrees. There appears to be a trend that the amplitude of this peak is less than or equal to the first peak value.

SUMMARY

The twenty to thirty degree range of elbow flexion angles commonly recommended for proper cane use assures the highest load sharing between the affected weight-bearing limb and the cane for normal subjects with an immobilized knee joint. However, this position may not be appropriate in situations where hand or wrist involvement presents a problem for ambulation. The magnitude of the loads transmitted through the cane may be too large.

Positioning the elbow within the range of 36 to 47 degrees of flexion will not allow the subjects to exert the maximum possible load on the cane. This creates the possibility of reducing wrist loading and upper extremity complications while maintaining most of the weight-sharing at this submaximal loading.

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THREE DIMENSIONAL SHOULDER JOINT MEASUREMENT

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ABSTRACT

A system for measuring shoulder motion with six degrees of freedom has been developed. This paper discusses this system and the advantages it offers over a previously developed electro-mechanical goniometer with three degrees of freedom for measuring the functional range of motion of the shoulder.

INTRODUCTION

The shoulder is the body's most complicated joint complex. Previous researchers have used a number of methods to measure its motion, ranging from simple mechanical goniometers for measuring the movement of the arm in one dimension to ultrasound and cine techniques for measuring shoulder joint with three degrees of freedom (DOF) (1,2). This paper describes a novel system for real-time measurement of shoulder motion with six DOF.

BACKGROUND

Measurement and analysis of shoulder motion or motion of the gleno-humeral joint provides information which can be used for evaluation of shoulder function, evaluation of upper extremity function and diagnosis of shoulder pathology. A key requirement for implementation of shoulder analysis techniques is the development of a simple, non-invasive, inexpensive shoulder movement measurement technique. An electromechanical device (called the scribe), developed by our group, has been described in a previous paper (3). This device measures functional shoulder movement by tracking the position of the forearm in space. The subject is positioned in a standing frame and linked to the scribe's tracking arm. The path of motion of the distal end of the subject's arm can then be calculated and plotted based upon a Cartesian coordinate system centered at the position of the resting shoulder joint. Data collection and conversion is performed by an Apple II+ computer. The computer is also used to display orthogonal views of the arm's movement in real-time, and analyze the data off-line (4).

Although the scribe technique has proven useful in extracting preliminary data about shoulder motion, it does have a number of problems, these are:

1. The subject's shoulder must be maintained at a known position in space, this is accomplished by the use of a standing frame. The subject experiences some discomfort which limits the examination line and the prevention of normal body motion may influence arm motion.

2. The system is sensitive to position changes of either the scribe or subject. This leads to errors in measurement.

3. Arm movement is measured with only three degrees of freedom, constraining the analysis to gross functional motion. It is of great interest, for instance to isolate rotation of the humerus about its long axis and track motion of the shoulder complex relative to the trunk, but this requires an additional three DOF.

METHOD

New and inexpensive technology provides real-time movement measurement with six DOF. The 3Space Tracker from McDonnell Douglas is an electromagnetic system using new and inexpensive technology provides real-time movement measurement with six DOF. The system uses source-sensor couples. Relative position of a sensor with respect to the source is determined with six DOF. The technology is based upon the detection of emitted pulsed orthogonal electromagnetic fields (5). In this application, the source is mounted on a light and flexible body harness (see figure 1) such that the center of the source is located near the sternum. One sensor is positioned just behind the subject's elbow using a simple cuff arrangement (also shown in figure 1), near the distal end of the humerus. This harness and cuff arrangement gives the subject a great deal of freedom of movement. To reduce measurement errors, the source and sensors must be kept away from large metal object or equipment that emits electromagnetic radiation (eg. computers).

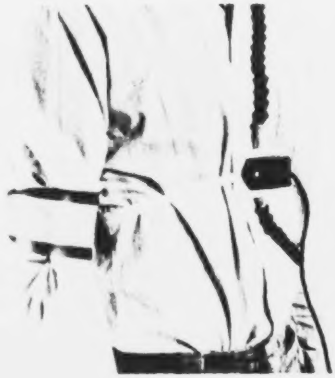

Figure 1. Mechanical interfaces for the source and sensor using a flexible body harness for the former and molded cuff for the latter (the sensor is positioned in the cuff just behind the elbow).

A second sensor is used to measure anatomical landmarks needed for configuring the measuring system. In order to provide continuity of between the software packages developed for the scribe system and this new measurement technique; we have adapted the data collected from the 3Space Tracker to ensure compatibility with the existing analysis software. The Apple computer communicates with the 3Space Tracker via an RS-232C interface operating at 19200 baud. The communication protocol for the 3Space Tracker provides a number of built-in operations useful in increasing the performance of this measurement system.

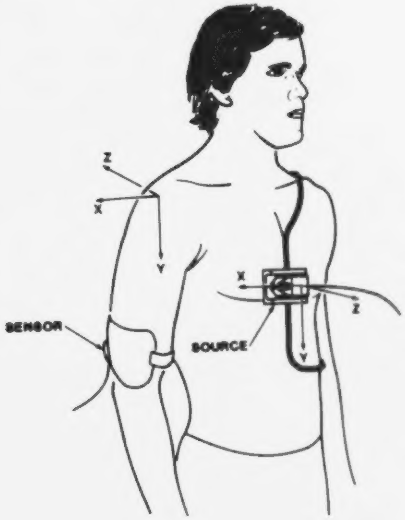

Figure 2. The measurement coordinate system must be moved from the center of the source to the resting position of the shoulder joint.

The diagram shown in figure 2 shows schematically the measurement situation when using the 3Space Tracker. Note that the origin of the coordinate system is based at the electromagnetic center of the source. In order to produce data which is both anatomically signifigant and compatible with the scribe system, the origin of the measurement system must be moved and rotated to match the orientation of the axis shown at the shoulder. To perform this operation, the second transducer is used to indicate the location of the top of the gleno-humeral joint. A bubble level and a pointer ensure that the coordinate system is appropriately aligned with respect to the body. The alignment procedure involves simply reading the position of sensor 2 then sending an align command to the 3Space Tracker.

Figure 3 illustrates a problem associated with the offset of sensor 1 with respect to the center of the humerus. The length and orientation of the line between the center of the humerus and the center of the humerus is calculated and used to correct the data collected about the position of sensor 1. This is done by measuring the position of sensor 1 while the humerus is rotated over 45 degrees. The center of rotation and the tilt of the transducers are used to calculate the radius of the correction factor required to move the measuring point of sensor 1 to the center of the humerus. While the data is collected from sensor 1 it is corrected for its offset relative to the center of the humerus.

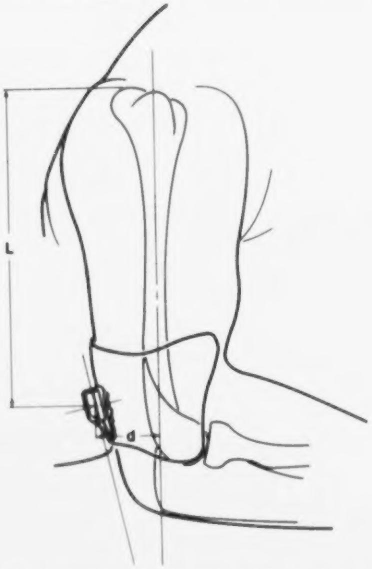

Figure 3. Shown here is the offset error (d) due to the positioning of sensor 1.

The net result of this adaptation is the replacement of the electromechanical scribe system with the 3Space Tracker. Presently only the three DOF are used to represent motion of the humerus relative to the trunk. Information about the rotation of the humerus and other angular data will be calculated using all six DOF.

RESULTS

A study of normal subjects has been conducted with the scribe to validate the measurement system and develop a normative data base. In addition, patient studies have been initiated to quantify changes in functional shoulder motion associated with known pathology. The objective of these studies is to provide an objective measure of response to treatment based upon functional motion of the shoulder. After an initial setup procedure, the subject is asked to slowly rotate his/her arm in as wide an arc as possible. After two dry runs, the data is recorded for several revolutions. As the information is being recorded, it is displayed on the Apple's screen. This display shows the three orthogonal views of the movement of the end of the arm: frontal, saggital and coronal. Figure 4 (a) shows the typical tracings for a normal subject while figure 4 (b) show the tracings from a subject suffering from adhesive capsulitis. Although some differences are qualitatively apparent from reviewing the loci of motion, specific quantitative parameters have been extracted to

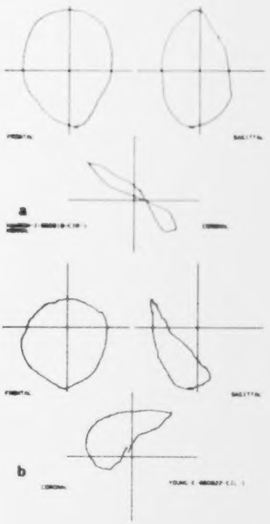

Figure 4. Typical loci of motion for two subjects a) normal and b) adhesive capsulitis.

permit statistical comparisons. The determination of the solid angle of revolution (SAR) subtended from the nominal shoulder center is one such example. By calculating the SAR for each subject a simple number can be used to compare the function motion of each shoulder joint. For instance the SAR for the patient who created 7(a) is 5.69 steradians, while the SAR for the patient who created 7(b) is 2.80 steradians. A correlation of SAR calculation and physiological dysfunction has yet to be shown.

DISCUSSION

Although results using the scribe have not yet shown any obvious, repeatable correlation with shoulder condition, it must be made clear that we have only been using the SAR calculation. Other paramters of motion may yet prove significant discriptors for either monitoring change or diagnosing pathology (i.e., changes in velocity during motion are examined). With its improved accuracy, ease of use, and six DOF, the 3Space Tracker system offers the possibility of calculating a wideer range of parameters. For instance, the position of the ball of the humerus in the shoulder joint can be calculated and tracked in space. This will give an indication of the contribution of the scapular-thoracic component of the shoulder movement. Measures of axial rotation of the humerus during the range of motion tests may assist in guiding treatment selection. As well, other rudimentary analysis of the range of motion information are possible. These include: velocity calculations, contour irregularity analysis of the range of motion path and simple length of path calculations.

CONCLUSION

The McDonnell Douglas 3Space Tracker has been adapted to measure shoulder movements. This arrangement gives the subject a good deal of freedom of movement; while relative motion of the whole humerus may be measured using all six degrees of freedom of the 3Space Tracker. Although present range of motion studies using the scribe and the solid angle of rotation calculation have not yet shown statistically significant differentiation of shoulder condition, the 3Space Tracker offers the possibility of calculating new parameters to assess shoulder function.

ACKNOWLEDGEMENTS

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USING THE OCCUPATIONAL THERAPY COMPREHENSIVE FUNCTIONAL ASSESSMENT (OTCFA) TO EVALUATE THE EFFICACY OF TECHNOLOGICAL INTERVENTION IN REHABILITATION

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ABSTRACT

Functional assessment in rehabilitation medicine and in rehabilitation technology has received vital research and development attention in the last few years. In the early 1980s, NIDRR supported the priority of quantitative assessment, and rehabilitation engineering centers and agencies have since produced assessment technologies, including Tufts REC, CP Research Foundation of Kansas, Assistive Device Center in California, Dallas Rehabilitation Foundation, MIT REC, University of Minnesota REC, Words+). Additionally, teaching and resource textbooks have been developed focused on the area of functional assessment specific to rehabilitation (Bolton & Cook, 1980; Halpern & Fuhrer, 1984; Granger & Gresham, 1984). The excellent rationale behind this recent attention to functional assessment is rooted in the need for making clear, concise, expedient and accurate decisions in the health care service delivery system. It is acknowledged that without the ability to implement assessment instruments with documented reliability and validity, the profession can only rely on intuition, personal experience, and individual clinical judgement for making decisions. As with most of the disciplines in rehabilitation, the field of rehabilitation technology traditionally has assessed its success based on individual service delivery results in a less than organized and consistent manner.

In the early 1970s, the Occupational Therapy Association acknowledged the significant inconsistency and splintered approach of assessment in occupational therapy. At that time, they began sponsoring research to evaluate the significance of the problem and implement some strategies for assuring a better continuity of evaluation between service delivery settings and instituting a more comprehensive approach for evaluating the efficacy of therapeutic intervention. The most recent step in the development of a better comprehensive performance evaluation for occupational therapists is the formulation of the constructs and content in the Occupational Therapy Comprehensive Functional Assessment (OTCFA). The significance of the OTCFA to rehabilitation technology is that it provides a method for documenting the efficacy of technological intervention.

REHABILITATION TECHNOLOGY AND ASSESSMENT

Historically, technology and assessment have interrelated in two primary ways. First, assessment methodology in rehabilitation is frequently dependent on technology to perform the acquisition of accurate and cost-effective measures. For example, in the measurement of grip strength, more than nine different brands of dynamometers have provided an objective method of measuring grip strength and are being used in rehabilitation clinics throughout the country. Without the technological contribution of the dynamometer, grip strength would continue to be measured with inaccurate procedures (Smith and Benge, 1985). The second major relationship between technology and assessment deals with the fabrication and implementation of technological devices, systems, and adaptations as therapeutic interventions. As technology is used in service delivery, it is becoming more and more critical that we understand and document the true efficacy of providing the technology.

Much of quantitative assessment emphasis in recent years has been toward the first type of technology and assessment interaction. A review of the research and development progress reports in the 1986 Veterans Administration Rehabilitation R&D Progress Reports highlights work in physiological monitoring devices, physiological surveillance equipment, computer automated systems for functional assessment, etc. These are all examples of the first interaction between technology and assessment.

Research documenting the efficacy of using various technological interventions in the field of rehabilitation is more rare. Part of the history behind this is that technology tends to have a high face validity, and it is easily recognizable for its potential. Therefore, a systematic, quantitative, scientific measure of its effectiveness has not seemed to be necessary. Also, emphasis in the area of rehabilitation technology has been in research and development of new technologies as opposed to assessing the clinical utilization of the potential technological interventions. This phenomenon is certainly not confined to the area of rehabilitation technology; virtually all of the health care related service delivery disciplines can describe the same scenario. Acknowledging this fact, and the notion that even if we wanted to measure the efficacy of our technologies we have yet to develop a consistent method for evaluating the contributions of a given intervention using a standard method which can eventually correlate and compare technical methodologies, the substantial interest in functional assessment over the past decade or so has prompted statements about functional assessment being a new specialty within the rehabilitation field (Granger & Gresham, 1984).

Historical and recent work in the area of rehabilitation assessment has produced countless numbers of instruments and approaches for assessing the outcomes of rehabilitation interventions. One of the problems assessments have always encountered is their limitations in scope. This results in constraining the application of the instruments to particular situations and prevents using existing instruments as a comprehensive and common measure for assessing, correlating and comparing. Basically, these assessments are limited by their construct and content scope in three ways.

Many assessments are limited by the population for which they were developed. For example, there is a handful of functional assessments developed specifically for use with the population of individuals who have had a stroke (Ottenbacher, 1980). Assessments in fact have a tendency to be categorized by the populations with which they are intended to be used (Granger & Gresham, 1984).

The second way assessments tend to be limited in scope is by the setting in which they were introduced. Many assessments are developed particular to the type of health care service that is provided within the organization. An example of this limitation is the instruments which focus on long-term care and lean toward a gerontological orientation (Pfeiffer, 1978). Another example is scales that were made particularly for acute care (Dubowitz, 1981). Perhaps one of the most recent examples of the limitation due to setting orientation is the FIMS (Functional Independence Measures) being developed by Granger, Hamilton and Sherwin (1986).

The third way functional assessments are limited in scope is through the functional area they assess. There are many evaluations, for example, that focus specifically on hand function (Mathiowetz et al., 1985, and Jebsen et al., 1969). Other tests, such as the Barthel (1955) , Katz et al. (1963), and Klein-Bell (1982), are examples of functional assessments that are limited to basic self-care skills.

These three ways that functional assessments are limited in scope point out the difficulty in selecting any particular evaluation tool for assessing a technological intervention. For example, if one were interested in assessing the contribution an automatic page turner has on the overall function of an individual, one would be hard-pressed to locate an adequate assessment that would really describe the impact of introducing this piece of technology to an individual's life. The Occupational Therapy Comprehensive Functional Assessment (OTCFA) was conceptualized specifically to integrate the various aspects of functional assessment and provide a standard, generic and comprehensive method for assessing the overall performance of an individual, including the technological equipment and environmental factors which contribute to performance.

THE OTCFA

The OTCFA is currently in the middle of its development. The past year and a half has focused on substantial work in the area of developing a sound construct and content for the assessment. Occupational therapists throughout the country, representing all the service delivery areas of occupational therapy, have been intimately involved in providing discussion and feedback to the project team. Consequently, the early phases of the OTCFA development have been very iterative, with discussion of concepts, terminology and general organization, and multiple revision phases of the OTCFA instrument. The belief is that without a solid construct and content foundation for the instrument, application would be extremely limited.

The overall conceptualization is a hierarchical model of functional performance. There are four levels, with a second dimension being the environment (see Figure 1). The overall model particularly assesses capabilities and skills as they relate to overall performance in activities. This model is unique in that it integrates high level activity functions such as basic self-care activities, home-making activities, vocational and avocational with the integrated skills which are necessary to adequately perform the activities, with the component abilities which provide the basic elements to achieve the skills necessary to perform the activities. In this conceptual model of functional assessment, not only is it able to highlight the specific activities with which an individual is having problems, but also what sets of skills are the major contributors to the difficulty with the activities and finally what problems with the component abilities and how they are contributing to the deficits of integrated skills. The environment is viewed as a second dimension as opposed to simply categories within the performance areas, because all social, cultural and physical environmental factors do not stand alone, but directly affect performance on the higher level activities, the next level integrated skills, and the lowest level component abilities.

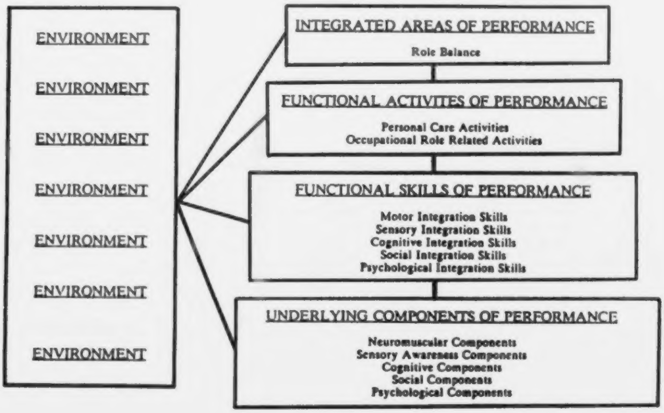
The full scale OTCFA includes five levels, fourteen major areas, and 117 detailed categories of function. Specific examples on the activity level include dressing, eating, reading, writing, community mobility, and household repair. Examples of the categories on the skill level include fine coordination, gross coordination, and specific problem solving skills, such as identifying that there is a problem. Examples on the component level include muscle strength, passive range of motion, pain, visual acuity, and tactile sensation. Examples of the categories of the environment include financial resources, medical resources, transportation resources, orthotics, and adaptive equipment. It can be pointed out that while community mobility is an activity that is performed, transportation is not an activity, but an environmental factor of available methods, which have an impact on the capabilities of community mobility. The entire OTCFA applies similar relationships as this mobility/transportation differentiation to tease out the exact nature of an individual's performance and relate the reasons for problematic performance directly to those activities.

The implications of the OTCFA in the area of rehabilitation technology are many. Two are particularly worth noting here. First, the OTCFA is able to point out the exact contribution that a technological device is making to a person's overall performance. Some types of devices, for example, certain types of hand and wrist splints, do nothing to contribute to any focal activity but more specifically may stabilize a joint or joints which permits a higher level set of skills in hand function, which in turn contributes to an increased performance of many activities. On the other hand, a particular adaptive device such as a rocker knife permits an individual to use one hand for primarily one activity, that being eating. This low technological device does not generalize to other areas of performance. It becomes an activity-devoted device.

A second implication of the OTCFA in regard to rehabilitation technology assessment is its sensitivity to document changes in overall human performance. Sensitivity in functional assessments can be obtained in two methods. One is to take any category of function and break it down into a finely graded scale. For example, a team functional assessment in California breaks down every category of impairment into 100 points. This successfully increases the sensitivity of the scale, and can document very small changes in that particular functional domain. Another method of increasing sensitivity,

Figure 1

RELATIONSHIP OF FUNCTIONAL ASSESSMENT AREAS


ENVIRONMENT
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ENVIRONMENT
INTEGRATED AREAS OF PERFORMANCE
Role Balance
FUNCTIONAL ACTIVITES OF PERFORMANCE
Personal Care Activities
Occupational Role Related Activities
FUNCTIONAL SKILLS OF PERFORMANCE
Motor Integration Skills
Sensory Integration Skills
Cognitive Integration Skills
Social Integration Skills
Psychological Integration Skills
UNDERLYING COMPONENTS OF PERFORMANCE
Neuromuscular Components
Sensory Awareness Components
Cognitive Components
Social Components
Psychological Components

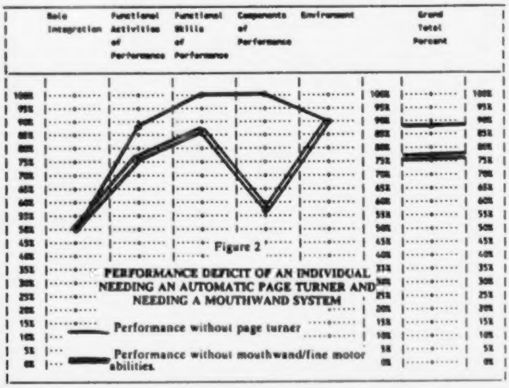

Figure 2

PERFORMANCE DEFICIT OF AN INDIVIDUAL NEEDING AN AUTOMATIC PAGE TURNER AND NEEDING A MOUTHWAND SYSTEM

which more easily retains high reliability, is to increase the number of categories that are being considered, as opposed to the scale within each category. The Klein-Bell ADL scale (Klein & Bell, 1982)) is an example of this method to increase sensitivity. Their scale focuses on basic self-care skills, and documents 170 categories of behavioral function. The OTCFA uses the second method to maintain its sensitivity to change, by incorporating its 117 categories.

The OTCFA provides a set of graphs which consolidate the performance data into summary information. These graphs depict the integration and sensitivity of the OTCFA and the application to technological intervention.

Line 1 of Figure 2 illustrates the OTCFA graph displaying the potential results of introducing use of an automatic page turner into a person's environment. As can be seen, the influence of a page turn is primarily with the second level, which focuses on activities. Additionally, since the need for a page turner falls within the environmental dimension, the environmental area reflects that there is a need in this area. Another example is illustrated in Line 2 of Figure 2. This describes the functional status of someone who does not have any motor function of the upper limbs, and thus has no direct physical mechanism for manipulating his environment. Here, we can see what the individual's status before the introduction of a technological device, and then subsequent function of the individual with a mouthwand system in use. Both of these illustrations have specifically isolated only the deficits relevant to the page turner or the mouthwand system in order to point out the sensitivity and dispersement of function within the OTCFA. In reality, individuals would virtually never exhibit such a simplistic functional picture, but this demonstrates the specific impact of a technological need.

OVERALL IMPLICATIONS OF THE OTCFA ON TECHNOLOGY

Rehabilitation technology, in parallel with all of the other rehabilitation disciplines, is being pressed into collecting data demonstrating the efficacy of the technological interventions. The OTCFA provides one method for approaching the measurement of overall effectiveness of any technology. The OTCFA performs this measurement function using a comprehensive, hierarchical designed assessment for specifically isolating the contributions any intervention has for an individual. The OTCFA to date is within the piloting stage, and thus continues to be under development. The past year and a half has focused on formulation of appropriate construct and content validity concepts, understanding that if a careful up-front process is used, the instrument will be much more effective for its purposes and statistical validity and reliability studies will be confirmed. It is anticipated that the nation-wide pilot studies, subsequent revision of the instrument, development of instructional materials, including a teaching videotape, identification of test-retest reliability and intra-rater reliability will be completed by mid-1988.

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Special Interest Group 6

Service Delivery Policy

Chair: John H. Leslie, Jr., Ph.D.

APPROACHING TECHNOLOGICAL SUPPORT AS A LIFELONG NEED: WHY REHABILITATION TECHNOLOGY SERVICES NEED TO BE SUSTAINED IN THE COMMUNITY

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ABSTRACT

There is increased attention being focused on the rehabilitation technology business and the service delivery aspects of technology support systems. With the increasing availability of community based, private sector technology services, it may be counterproductive in the long run for government agencies to continue to develop in-house services which would impede the development of private sector initiatives. If an agency such as Vocational Rehabilitation or Special Education remains the primary source for technology services, disabled individuals who have lifelong technology needs may have no place to go for their services when they are no longer agency clients. Coordinated planning must take place on a statewide level to assure that comprehensive services will meet the lifelong technology needs of disabled citizens.

INTRODUCTION

A disabled person's need for technological support is usually a life long need. (You may only need to learn to drive once; but if you need one adapted vehicle, you will probably continue to need adapted vehicles. If you require a motorized wheelchair, it is not likely you will outgrow that need.) There are significant differences in planning for long term vs short term needs. The rehabilitation system has traditionally focused its attention on shorter term and/or time-limited types of interventions. However there is now an increased recognition of the importance of ongoing, coordinated support systems such as independent living and supported work. Technological support services and systems play an important role in these new trends that are redefining the entire habilitation/rehabilitation system. There has only been a single generation of severely disabled persons who have benefitted from significant technological intervention. We are only now beginning to get a sense of the longer term issues that a comprehensive support system must address -- such as: Where does the next adapted vehicle come from? How do you upgrade computer adaptations to remain competitive in the workforce as more sophisticated technology becomes available? What is a rehabilitation agency's role when former clients find they need financing for subsequent generations of equipment?

DISCUSSION

Rehabilitation engineering/technology services is a major new initiative in the Rehabilitation Act Amendments of 1986. As defined in the new law, "the term rehabilitation engineering means the systematic application of technologies, engineering methodologies, or scientific principles to meet the needs of and address the barriers confronted by individuals with handicaps in areas which include education, rehabilitation, employment, transportation, independent living, and recreation."

The field of technology services is emerging from several different arenas, responding to different demands and varying needs. Some programs have emerged from the traditional field of prosthetics/orthotics, others from the durable medical equipment industry. Interest in job site modification spurred some; others developed along with advances in technology, e.g., augmentative communication, or specialized vehicles. Some have a strong architectural/design flavor; others respond to certain populations, such as farmers or children. Some are for profit; others are in the public sector. Some are heavily oriented to information provision, while others primarily sell quality assurance and case review. The important thing to remember is that there are an increasing number of rehabilitation technology services available, even though they may not yet identify themselves in traditional rehabilitation jargon.

The increased complexity, variety, and potential benefits of technological support demand that we learn to take advantage of methods that will ensure we are getting the most value from available resources. It is fortunate that the new Rehabilitation Act Amendments do not limit the state VR agencies to any particular approach in their inclusion of rehabilitation engineering/technology services. It provides these agencies with the opportunity to plan for an approach to rehabilitation technology service delivery that is consistent with emerging trends in rehabilitation practice as well as with changing consumer expectations and the new environments in which rehabilitation services are provided.

State vocational rehabilitation agencies have been purchasing technology services for years. Many of them have clearly written procedures under such headings as: van modification, home modification, prosthetics, sensory aids. They have tried many different and innovative approaches to incorporating technology services into their programs. These range from training counsellors to be more aware of the potential benefits of appropriately applied technology and teaching them to be more informed "shoppers" for technology related services, to hiring professional engineers within the agency who actually provide the assessment and technology fabrication services.

Based on the extensive range of activities that can be included in the scope of engineering/technology services, it is puzzling to see state agencies still trying to develop in-house engineering capacity when they are not likely to develop, for example, an in-house prosthetics staff, or an agency employed van modifier. A few state VR agencies have developed in-house engineering and fabrication capability. Doubtless, many of these efforts were fueled by the frustrations of limited, or seemingly nonexistent, sources from which to purchase the services which the agency saw it needed. However, technology services are becoming increasingly available. It may no longer be necessary or even desirable for a state VR agency to try to fill this gap in technology services by developing an internal service delivery capacity. It may actually be counterproductive in the long run for government agencies to continue to develop in-house services which would impede the development of private sector initiatives. If an agency such as VR remains the primary source for technology services, disabled individuals who have lifelong technology needs will have no place to go for their services when they are no longer agency clients. If agencies cannot currently find the required services in the community, it may be necessary for them to actively foster the development of community based rehabilitation technology service delivery capacity, as they plan for the long term needs of disabled citizens. This type of priority becomes even more feasible as several different agencies within the state recognize the need for encouraging such private sector enterprise. (Agencies with responsibility for rehabilitation, developmental disabilities, special education, aging, etc. are some of the more obvious ones to get involved.)

Rehabilitation technology service delivery is an emerging field. There is no one, definitive model or exemplary program that can or should be copied as states attempt to meet their new mandate. Before any action is taken, it is essential that each state assess the need, identify currently available resources and set realistic goals. Planning must take place at the state level to assure that comprehensive services will meet the lifelong technology needs of disabled citizens. It is important to keep in mind that the state Vocational Rehabilitation Agency is only one of many programs that need to be involved in planning for comprehensive technology services for disabled people of all ages. Unified planning will reduce duplication of effort as agencies within the state begin to develop mechanisms for implementing appropriate technology services over the next years. It will also enhance the capacity for development of private sector rehabilitation technology services as the market for these services is better defined.

Although it may initially be a somewhat more complex procedure to find ways to get services established in the private sector, in the long run, it is bound to be more cost effective for everyone involved. Disabled individuals will be able to obtain needed technology whether or not they are eligible agency clients. State agencies will be able to buy only what is needed, when it is needed; a capability that is usually lost when they are trying to provide specialized services with their own personnel, and a strong and responsive private sector strengthens the state's economic base.

RESOURCES SUPPORTING PLANNING/IMPLEMENTATION EFFORTS

There are several Department of Education, Office of Special Education and Rehabilitation Services (OSERS), funded projects that will assist the planning and implementation efforts for rehabilitation technology services:

**The National Institute on Disability and Rehabilitation Research is funding a Research and Demonstration Project at the Electronic Industries Foundation to "Develop an Integrated Approach to the Development of a National Rehabilitation Technology Service Delivery System". Project investigators have been studying the issues discussed in this article, and others related to encouraging the development of coordinated rehabilitation service delivery systems. As part of the grant, a National Symposium on Rehabilita-

tion Technology Service Delivery was held in Arkansas in September, 1986. Twenty-nine exemplary service delivery programs were invited to participate. They were selected to represent the broadest range of activities on a continuum of approaches to technology services. This symposium drew attention to the growth and increasing availability of both technology and technology related services. Based on information obtained at the symposium, RESNA will be producing a Guidebook to Rehabilitation Technology Service Delivery, available late '87. It will contain information on service delivery program development, business practices, financing strategies, marketing, outreach, etc. as well as overview material on existing models, exemplary programs, and available resources. RESNA has also compiled a nationwide listing of programs providing rehabilitation technology services.
**The Rehabilitation Services Administration (RSA) supported Thirteenth Institute on Rehabilitation Issues, has developed a document, Rehabilitation Technology. It includes a chapter on Policy Issues in Providing Rehabilitation Technology Services: A Guide for State Rehabilitation Administrators and Policymakers, as well as the results of a national survey of Rehabilitation Technology Utilization in State Vocational Rehabilitation Agencies conducted by the Rehabilitation Engineering Center at the University of Wisconsin-Stout. There are several chapters devoted to information and resources necessary for technology case management by counsellors.

** The Rehabilitation Act Amendments of 1986 authorizes the establishment and support of Rehabilitation Engineering Research Centers (RECs) in Connecticut and South Carolina to "demonstrate and disseminate innovative models for the delivery of cost-effective rehabilitation engineering services to assist in meeting the needs of, and addressing the barriers confronted by, individuals with handicaps."

CONCLUSION

It is indeed exciting and encouraging to see the possibilities that technology holds for individuals with disabilities; and to be a part of the incorporation of technology services into comprehensive rehabilitation efforts. Planning, cooperative efforts between public and private sectors, and ongoing collaboration among all players will be the keys to developing and implementing standards of excellence which will ensure that disabled people will be able to obtain the technology support systems that enable full participation in American life.

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A GUIDEBOOK FOR ESTABLISHING & OPERATING A REHABILITATION ENGINEERING TECHNOLOGY (RET) SERVICE-CHAPTER 3 SUMMARY: PROGRAM DEVELOPMENT & OPERATION

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INTRODUCTION

This chapter attempts to provide specific suggestions or recommendations to individuals that have been assigned the task of establishing or operating a RET service program. As with all guidelines this approach has its dangers. The primary concern is that most recommendations are biased by the experiences and situations unique to those who developed them. It should be further recognized that the nature, scope, and degree of success or failure of any new program is dictated largely by the past experiences, interests, and commitment of those in the leadership roles; and by the strong influences of the environment in which the program has been built. Within the sphere of these above realities the authors attempt to provide guidelines for program development and operation that draws on the experiences gained in approximately twelve existing programs. These programs are representative of the models described in chapter one. These models are: 1) DME distributor; 2) Department in a comprehensive Rehabilitation Program; 3) Center in a University; 4) State Agency based program; 5) Private RE Firm; 6) National non-profit Organization; and 7) Volunteer based organizations.

The following is a summary of the contents of each subsection.

ANALYSIS OF ENVIRONMENT

Given todays environment it is evident that rehabilitation is quickly moving into the arena of "big business". This means that business practices can be used to facilitate the planning and implementation of the program. The first stage of the planning process is to conduct a detailed analysis of the environment in which the program is to operate. The business approach to this phase is termed a "market analysis". The guidelines for such an analysis area outlined in Chapter Six - Marketing and Outreach. Factors to be considered specific to program development are:

* What is currently being provided and by whom?
* Who and where are the referral sources?
* Numbers projections?
* Who wants the service and why?
* Payment sources and authorizers?
* Existing clinics/travel distances?
* Technical resources/shops, DME, Inhouse, Materials, Equipment?
* Clinical resources/therapy, nursing, medical?
* Clerical resources/secretarial, accounting?
* Chain of authority/how supportive, level of commitment ($)?
* In what type of model will the program function (Chapter Two)?

PROGRAM PLANNING

The importance of both long and short term planning can not be over emphasized. It is the process by which the hard questions are asked and hopefully tentative directions formulated. Its the means by which critical concepts are communicated to others and approvals and support are obtained. It provides the 'roadmap' against which priorities can be weighed when the pressures mount to be 'all to all people'. It contains ones best estimates on cost versus income projections, when profitability can be expected, and the means for communicating these projections to those providing the startup capital and other resources. It provides the justification for space, equipment, and staff requirements to meet the anticipated client flow. And finally, the plan contains the details of the startup phase including the strategy for marketing the program to the community.

PROGRAM DEVELOPMENT

Once the basic plan has been generated and gained approval, focus can then be directed towards developing the details of program operation. Again, it is recognised that each environment may be a variation on one or more of the basic models outlined in chapter two. However, for almost all developing programs the following structural elements will eventually need to be addressed; and its recommended that the timing be 'sooner rather than later'.

* Facilities Development
* Staff Recruiting and Development
* Accounting and Client Data Base Systems
* Client Flow Organization
* Developing the Fee Schedule
* Communication with Clients/Referral Sources/ Other Programs
* Program Evaluation and Financial Monitoring (Critical Indicators)
* Outreach Activities (How much and with what returns)
* Ongoing Public and Professional Relations
* Policies and Procedures Manual

PROGRAM IMPLEMENTATION

The day has come. Its time to attend to your first clinic or attend your first rounds or see your first client. The end result will most likely be a commitment to deliver a service within an expected time frame; and unless you can give services away, at a specified charge. What can be done to optimize the changes of success in both the long and short term?

The following topic areas will provide suggestions and general guidelines related to:

* Clarifying and Documenting Commitments
* Buy/Modify/or Design Decisions
* Information Sources/Solutions, Equipment
* Billing and Collections Strategies
* Quality Control/Legal Issues
* Maintenance and Repair Policies
* Inventory/Storage Decisions

EXEMPLARY MODELS FROM THE FIELD

This subsection presents the survey results from twelve sites. The survey instrument has been designed to obtain descriptive information as well as solicit hindsight comments that are based on actual experiences of individuals who developed the programs. The information presented will address the following issues:

* Brief Description of Existing Models (6)
* Description of Two Programs Per Model
  - Critial Start-up Factors
  - Hindsight Comments--How would one do same today?
  - Common Start-up and Other Factors (Things that seem to work)
* Other Variations of Delivery Models
* Summary Comments and Suggestions

PROGRAM EVALUATION AND FINANCIAL MONITORING

This subsection deals with the evaluation of program performance and suggestions for positive action when problems arise:

* Monitoring the Critical Indicators
* Referrals and Income Fall Below Projections
* Identifying the Problems
* Taking Corrective Action
* Communicating with those in Authority
* Outstanding Accounts/Write Offs

SUMMARY AND RECOMMENDATIONS

This final section will summarize the key points above and again issue cautions regarding the perceived limitations of the guidelines.

REFERENCES

Additional reading on program development and operation will be referenced.

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DELIVERY OF REHABILITATION TECHNOLOGY SERVICES IN AUSTRALIA

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ABSTRACT This paper gives an overview of technology delivery services for people with physical disabilities in Australia. A historical evolution can be seen, from fundamental technology to computer technology and information-based services. The range of service providers accessible to disabled people is outlined, and the work of the Rehabilitation Engineering Department, Regency Park Centre for Young Disabled, is described more fully. Some current trends are described and possible future directions are hypothesised.

INTRODUCTION

Australia is a Federation of six States and two Territories. The delivery of health services is primarily a responsibility of the States. However, a network of veterans' Repatriation Artificial Limb and Appliance Centres (RALAC's) was established as a Federal responsibility in each State early this century. In 1973, under the Commonwealth Government's Free Limbs Scheme, those Centres became responsible for the provision of artificial limbs free of charge to all members of the community. Notwithstanding this, State hospitals and rehabilitation centres retain the primary responsibility for the provision of orthoses, giving rise to a uniquely Australian division between prosthetics and orthotics.

During the 1970's, Independent Living Centres were established in the various State Capitals, staffed primarily by occupational therapists, to provide information on commercially available aids and appliances. A voluntary organisation, Technical Aid to the Disabled, was also established in most States, and continues to provide technical assistance on a volunteer basis. More recently, rehabilitation engineering centres have been established in three States, and more are planned. Special Education Resource Units in the various State Education Departments are concerned with computer technology in classrooms. The private sector involvement is by means of prosthetics and orthotics practices, wheelchair manufacturers, and import agencies. University-based research in rehabilitation technology is well established and, more recently, some companies have begun to market Australian-designed products for both local and overseas markets.

TECHNOLOGY SERVICE PROVIDERS

A person with a physical disability in Australia can receive technology-related services from a number of service providers. Disabled people therefore need to know where they can obtain appropriate services. Figure 1 shows the person with a disability and the various technology service providers. Over 80% of Australians live in or near the State capitals so the organisations shown in Figure 1 are essentially repeated in each State with some elements missing in some States.

Figure 1 does not show, and this paper will not address, the various available funding sources, permissible prescribers, and the significant level of consultancy and referral from health professionals which is necessary to make the system work.

A brief description of each of the elements accessible to the person with a physical disability follows. The author's home State of South Australia will be emphasised, and significant differences in other States will be mentioned.

Disability Information & Resource Centre (DIRC). DIRC is a recent development, having commenced operating in 1983. It provides information on disability and matters of interest to people with disabilities. It maintains a computer database on disability organisations in the State, and has an extensive library. Its staff of three in new purpose-built premises handles approximately 250 enquiries by phone, letter and in person each month. It also provides a resource for typing, photocopying, collating and other secretarial functions, and temporary office accommodation for individual disabled people and organisations.

Commercial Suppliers. Several companies market a range of products, many of which are imported Relatively larger volume items such as manual and electric wheelchairs are available from local manufacturers on a made-to-measure basis, in addition to the standard sizes and features available from import agencies.

Independent Living Centre (ILC). The Independent Living Centre in South Australia has staff of six in premises of 700 square metres. It displays some 1,000 rehabilitation products and maintains a card system with information, supplier and current cost on some 6,000 devices.

Technical Aid to the Disabled (TAD). TAD branches are now established in most States, and they comprise volunteers who design and construct aids for people with disabilities. TAD is a small operation in most States, e.g. 35 jobs were undertaken in our State last year. The largest operation is in Sydney, where there is a large network of volunteers and a central administration and library. This TAD is supported by government and other grants, and clients are charged for materials only. The costs of such an extensive system with a salaried executive are similar to the costs of a fully professional service.

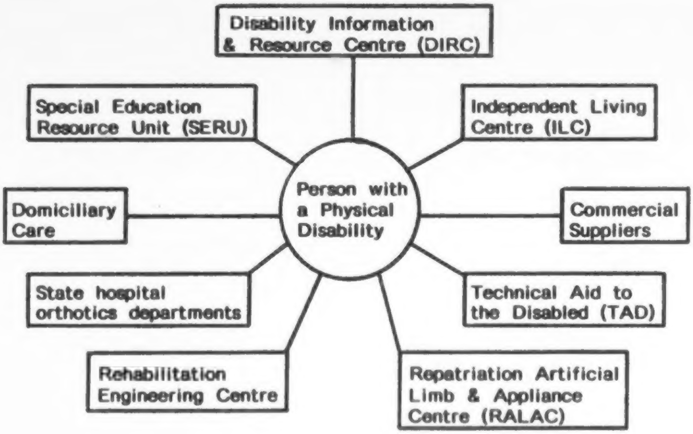
Disability Information & Resource Centre (DIRC)
Special Education Resource Unit (SERU)
Independent Living Centre (ILC)
Person with a Physical Disability
Domiciliary Care
Commercial Suppliers
State hospital orthotics departments
Technical Aid to the Disabled (TAD)
Rehabilitation Engineering Centre
Repatriation Artificial Limb & Appliance Centre (RALAC)

Figure 1: The person with a disability and technology service providers.

Rehabilitation Engineering Centre. Despite reports recommending further developments in rehabilitation engineering in Australia, only four Centres currently exist, located in Brisbane, Queensland, Perth, Western Australia, Sydney, New South Wales, and Adelaide, South Australia (1). The Centre at the Royal Perth Hospital has a long service and research involvement with pressure distributing seating and the recovery of failed internal joint replacements. More recent work includes shape sensing and the development of a gait laboratory. The REC at Royal South Sydney Hospital has concentrated on the provision of custom moulded seating and is also developing a gait laboratory. The REC in Brisbane has specialised in matrix seating. The REC in Adelaide will be described more fully in the next section.

State Hospital Orthotics Departments. The provision of orthotic services is through major State teaching hospitals and in South Australia there are orthotics departments at the Royal Adelaide Hospital, the Adelaide Childrens Hospital and the Queen Elizabeth Hospital, in addition to the orthotics service which forms part of the Rehabilitation Engineering Department at the Regency Park Centre.

Repatriation Artificial Limb and Appliance Centre (RALAC). The RALAC administers the Free Limbs Scheme so all artificial limbs are prescribed and approved by the RALAC's limb fitting medical specialist. Private prosthetic orthotic practices compete with RALAC staff in the manufacture and fitting of prostheses.

Special Education Resource Unit (SERU). The Special Education Resource Unit in South Australia employs two teachers to advise on the appropriate use of computers in classrooms with school-age children who have physical or intellectual disabilities.

Domiciliary Care. The government-funded Domiciliary Care organisations are responsible for seeing that people with disabilities are able to live in their own homes where possible, and this will often mean an occupational therapist advising on home modifications which can be carried out by their staff or by the public housing authority.

REHABILITATION ENGINEERING AT REGENCY PARK CENTRE

The work of the Rehabilitation Engineering Department at the Regency Park Centre for Young Disabled illustrates one of the elements in the overall technology delivery network. The overarching goal of the department is:

> **"We provide disabled people with appropriate technology for their needs. We share good ideas, make products available, and strive for quality in manufacture. We finance our work independently where possible."**

The department has a staff of seventeen, including three engineers, four orthotists, three orthotic technicians, a surgical bootmaker, two wheelchair maintenance staff, two electronic technicians and two secretaries. Facilities include an orthotics workshop, plaster-casting and plastic vacuum-forming areas, leatherwork and surgical footwear workshop, electronics display and trialling area and workshop, wheelchair maintenance area, storage area and reception and office space, in a total area of 500 square metres. Direct client services are provided in the areas of orthotics, footwear, special seating, wheelchair specification and maintenance, and computer and electronics design, fabrication and service.

A consultancy service titled the "Assistive Device Assessment Service" is available for clients from outside the Centre who request advice concerning wheelchairs and seating, communication devices, computers and other areas of need. Forms are sent to the referring agency seeking client information. Physiotherapists, speech pathologists and occupational therapists at the Centre will assess client abilities and needs. Approximately 7,000 jobs are undertaken each year, and approximately 20% of our clients are adult.

Research is undertaken to underpin and strengthen our client service work. Past research has included:

- studies of biofeedback (2)
- the development of a skill evaluator and trainer (3)
- the development of a crashworthy wheelchair and occupant restraint assembly, and the development of restraint standards (4)
- study of seating posture in cerebral palsy (5)
- study of postural supports in Duchenne muscular dystrophy (6)
- study of equinus progression in Duchenne muscular dystrophy (7), and
- a follow-up survey of client satisfaction (8).

Current research and development projects, some of which are described more fully in the Journal of Rehabilitation R & D Progress Reports (1986), include:

- voice recognition using the Apple IIe
- biomechanics of paralytic scoliosis
- respiratory muscle endurance training in Duchenne muscular dystrophy
- comparative evaluation of alternative wheelchair seating
- functional electrical stimulation in dropped foot conditions
- functional electrical stimulation in upper extremity muscles of spinal cord injured people
- design rules for access by disabled children
- a study of powered wheelchair controllers
- development of a trailable ablution unit
- development of a simple speech synthesiser
- wheelchair evaluation and performance testing
- microcomputers, including conducting a short course, evaluating Trine and acting as an agency for Adaptive Communication Systems
- development of a new light orthotic knee joint
- workplace modifications
- information technology
- development of a toy control program for the Apple IIe

DISCUSSION

This paper has presented an overview of the delivery of rehabilitation technology services in Australia. It presents a diversified picture.

The main trend, consistent with trends in the rest of society (9) is the shift from fundamental to computer technology. Evidence of this is seen in the increasing development of services in the areas of electronics and computers, and we anticipate an increasing use of environmental control units. Computerisation of information-based services is also occurring and the computerisation of the Independent Living Centre records should occur shortly. The increasing involvement of therapists in assessing disabled people for using assistive devices is a welcome trend, which will augment the policy of purchasing devices where possible, modifying where appropriate and fabricating only where necessary.

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THE AUTHOR

This paper is presented on the basis of the author's experience in South Australia as Head of the Rehabilitation Engineering Centre, Chairman of the Disability Information and Resource Centre, Board Member of the Independent Living Centre, past Executive Member of TAD, past employment in the RALAC system and ongoing relationships with the other elements in the system.

As Chairman of the National Committee on Biomedical Engineering of the Institution of Engineers, Australia, the author has sought to promote the development of rehabilitation engineering in Australia and this initiative will continue in future.

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THE DANIEL M. CARNEY REHABILITATION ENGINEERING CENTER - A UNIQUE SERVICE DELIVERY SYSTEM FOR PERSONS WITH DISABILITIES

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Rehabilitation Engineering Center

ABSTRACT

The Cerebral Palsy Research Foundation of Kansas, Inc. (CPRFK), has been seeking ways to serve the needs of persons with severe physical disabilities since 1972. Significant research efforts have been made in the area of seeking means to allow persons with severe physical disabilities to lead lives with independence through the utilization of technology. Provision of the technology has been through the Rehabilitation Engineering Center, a department within CPRFK, and having a working relationship with the College of Engineering at Wichita State University. The research has generated the need to find means to provide services to persons with disabilities. The recognition of this need prompted CPRFK to develop a unique facility to first evaluate the needs of disabled persons, and then to satisfy those needs through design and fabrication of appropriate devices. The development of the Daniel M. Carney Rehabilitation Engineering Center and its operations are presented and discussed in this paper.

BACKGROUND

The Cerebral Palsy Research Foundation of Kansas, Inc. (CPRFK), received the designation of a national Rehabilitation Engineering Center in 1976 by the National Institute of Handicapped Research (now known as the National Institute of Disabilities Rehabilitation Research). Basic research efforts have been achieved through a working relationship between the College of Engineering at Wichita State University and CPRFK. The core area of research has been in the area of seeking ways for persons with disabilities to find employment through the means of technology. The key to success of many CPRFK programs is rehabilitation engineering. CPRFK-sponsored programs such as The Timbers for housing, and Center Industries Corporation for employment, are a reality because of developments through rehabilitation engineering.

A significant result of the research has been the development of an evaluation system to determine the physical capabilities of disabled persons to perform work tasks. This system is called the Available Motions Inventory (1), and has been used to determine where engineering modifications are needed in order for a disabled person to be productive on the job.

The need to possess the means whereby to follow up the results of the research with services became apparent as more and more persons with disabilities were requesting the services. The recognition of this need by CPRFK has resulted in the development of a unique facility to provide the means to evaluate the needs, and, more importantly, then to satisfy those needs through the design and fabrication of appropriate devices. The name of this new facility is the Daniel M. Carney Rehabilitation Engineering Center. See Figures 1 and 2.

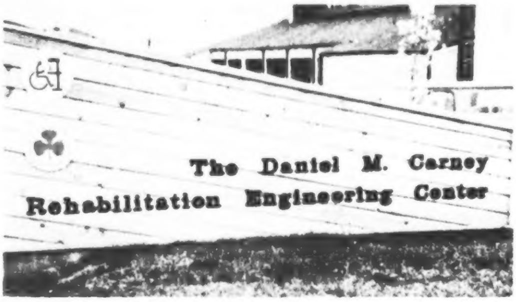

Figure 1: Facility Sign

The building houses nearly 11,000 square feet and is located on the site of CPRFK corporate headquarters and The Timbers housing complex. Aside from a community block grant amounting to 16% of the total cost, the entire underwriting of the cost of construction was made through contributions from the private sector. The facility is named after Daniel M. Carney, a long-time friend of CPRFK, and is currently chairman of the board of directors.

Figure 2: Building Exterior

FACILITIES

Offices and staff

Twelve offices within the building provide the working space for professionals who deal with the needs of persons with disabilities. The current staff is made up of six engineers of varying capabilities, two registered physical therapists, one physical therapy assistant, two persons who work with the social needs of clients, two persons who work in the evaluation of work abilities, one shop supervisor, two full-time technicians, and two part-time shop technicians. One office in the building houses computer and word-processing equipment.

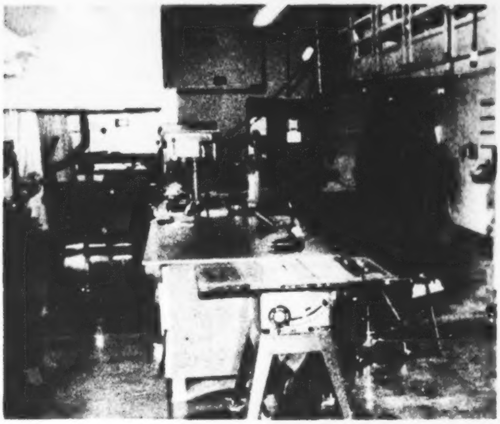

Figure 3: Engineering Shop

Engineering laboratory and shop
The engineering laboratory and shop consists of 2000 square feet on one floor plus a balcony of 900 square feet. See Figures 3 and 4. Full metal working capability plus welding, painting, and a wood shop, are contained therein. Significant work is carried out in the area of device fabrication, fabrication of workstation modifications, posture-control seating systems, and wheelchair repair (both manual and powered).

Work abilities evaluation laboratory
This area consists of two offices for staff, one room for testing cognitive capabilities, and one large room for testing physical capabilities. The equipment comprising the Available Motions Inventory is housed in this room. See Figure 5.

Classroom
This room is used for instruction of various kinds including the use of typewriters, word-processors, and calculators. Techniques for carrying out personal hygiene, and instruction in control of personal finances (including tax return preparation) are also taught. See Figure 6.

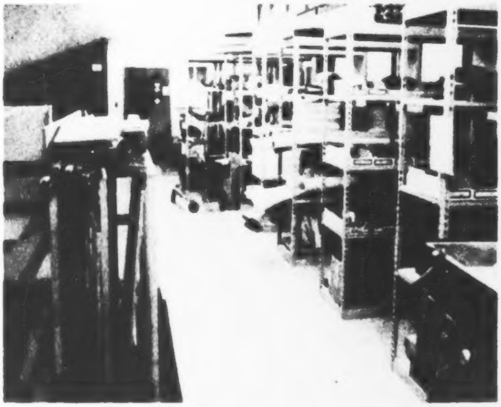

Figure 4: Shop Balcony

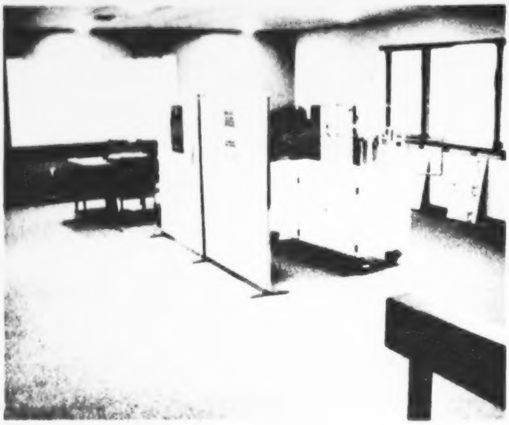

Figure 5: Work Abilities Laboratory

Physical therapy room
Several residents of The Timbers require physical therapy on a regular basis. Also, persons from the community can receive this service if required. One room within the facility is devoted to providing physical therapy. See Figure 7.

Gymnasium
A gymnasium of roughly two-thirds the size of a full-sized basketball court is contained within the facility. Two basketball goals which adjust in height are furnished. Boundary lines for several games are color-coded in the floor. Wheelchair soccer, volleyball, badminton, and paddle tennis are some of the games available. Residents of The Timbers and of the community use this facility on a regular basis in both planned and unorganized activities. See Figure 8.

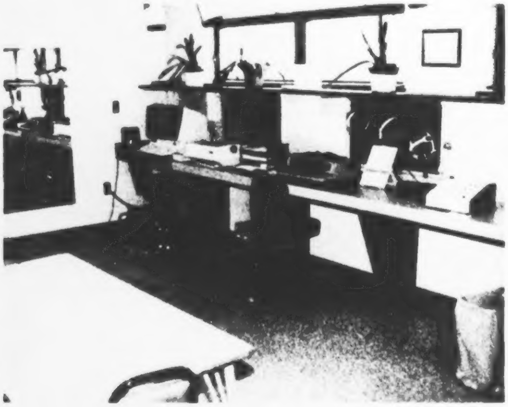

Figure 6: Classroom

Figure 7: Physical Therapy

Meeting and media room

One large room is used for meetings and media presentations. Video equipment, a projection screen, and chalkboard are available in this room which seats approximately 40 persons.

DISCUSSION

The reader quickly becomes aware that this facility contains much more than the capability to provide technical services. In the final planning, it became increasingly apparent that a multi-faceted building would best suit the needs of all the programs with CPRFK. However, it is felt that all of the functions of the facilities work quite well in harmony as the needs of persons with disabilities are evaluated and satisfied.

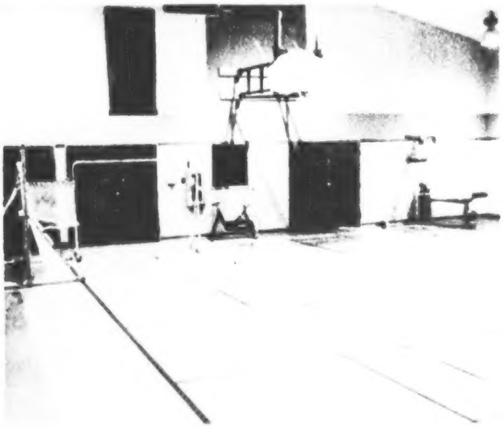

Figure 8: Gymnasium

The facility became available for occupancy in July of 1986. Since moving in, staff has been increasingly called upon to provide the various services for which the building was designed. The activity has reached such a level in this short period of time that staff members are already beginning to look to possible expansion of the size of the building (a possibility forseen by the building's designers).

It has become extremely apparent to the authors that facilities which are capable of providing service delivery to persons with disabilities are in insufficient supply. Perhaps the success that CPRFK is experiencing with this facility will encourage others to seek similar means to provide the services that are so badly needed.

ACKNOWLEDGEMENTS

The authors wish to thank the Cerebral Palsy Research Foundation of Kansas, Inc., and the National Institute of Disabilities Rehabilitation Research for providing the means for research and service delivery in behalf of persons with disabilities over the past several years. The work has been most rewarding.

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368

THE PHYSICIAN'S ROLE IN OBTAINING REHABILITATION TECHNOLOGY

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ABSTRACT

Rehabilitation technology designed to provide support, comfort and enhancement of body function is increasingly available, but not necessarily obtainable by persons with disabilities. Physicians frequently serve a key role in the access to, and payment for, appropriate technology. The physician must: (1) recognize the need; (2) verify disability status; (3) refer to appropriate service providers; (4) document the specific needs and specific solutions; (5) provide a prescription where required; and (6) review the status and function of the disabled individual with the assistive technology, documenting the improvement in function.

BACKGROUND

Rehabilitation technology encompasses a broad range of assistive devices designed to provide support, comfort and enhancement of body function for disabled persons of all ages. The range includes orthotics, prosthetics, seating and mobility systems, communication and environmental controls, and transportation modifications.

Much of the current technology has been developed in medical care settings by physicians working with engineers, therapists and technicians. As a result of the use of technology as an adjunct to medical and surgical care, the payment system has incorporated assistive devices into the medical service system, requiring a physician's prescription for documentation of need. However, as the categories and variations of assistive devices have increased, the physician may be unaware of the range of options available to solve a specific need. Specialists in rehabilitation technology can evaluate the individual functions of the disabled person, ascertain the specific activities which are desired by the person, and make recommendations about the options available. The physician will usually need to write a specific prescription, providing some medical data in justification of anticipated improvement in function.

Communication technology, environmental and transportation modifications and work-site restructuring have been developed in conjunction with educators, vocational counselors and adult disabled people, and are less clearly identified with the medical care system. However, physicians may be required to verify disability status for the person being considered for this technology, and, sometimes of greater importance, to verify the individual's capabilities for effective use of rehabilitation technology. The physician may need consultation from psychologists, occupational, physical or speech therapists, and rehabilitation nurses, as well as the vocational counselors mentioned above, in order to document the individual's needs and anticipated performance level.

PHYSICIAN'S ROLE

The physician must realize that the care of disabled people extends beyond acute medical intervention and the supervision of convalescence. Ongoing management involves assessment of residual function and selection of appropriate technology to support, protect and enhance the capabilities of the disabled person. Participation of the person and his or her family in the decisions is essential for success of the rehabilitation plan.

Physicians should function as team members with the disabled person and family, therapists and other professionals in selecting and obtaining rehabilitation technology. To learn the range of options the individual may have to be referred to local resources or a regional center for technology. Resources may include: local physical, occupational and speech therapists; local, regional or state crippled children services or developmental disability services; durable medical equipment suppliers; home health agencies; prosthetic and orthotic suppliers; and local voluntary agencies such as Easter Seal, United Cerebral Palsy Associations, et al. The state rehabilitation services are frequently helpful as well.

The physician's responsibility does not end with referral or with obtaining consultation from specialists in rehabilitation technology. It is still necessary to provide a prescription, documentation and advocacy for disabled people in obtaining the devices. This effort includes learning what funding agencies require as documentation before authorization is approved.

The physician assumes the role of facilitator, in part because he or she is the key to provision and payment, and in part because he or she is in the best possible position to know the disabled person's state of physical and mental function. If the physician chooses to delegate this responsibility, the disabled person and family should be clearly aware of who will assume it, and whether the physician will remain available for re-evaluation and ongoing support as necessary.

After delivery and practice with the assistive technology, the individual needs to be reassessed by the physician to verify changes related to device use and to identify problems. Sometimes new problems arise as function improves, and of course the performance of the equipment should be monitored, either by the physician or a person from whom information can be received. Questions which may occur are: How does the individual feel about himself or herself when using the device? Does she/he feel conspicuous, awkward, "more disabled" in appearance? Does the value of the device in improved function outweigh the appearance? IS THE DISABLED PERSON USING THE DEVICE? Sometimes the physician is the last person to know that a brace, cane, prosthesis or communication device is comfortably resting in a closet. If this happens, it is important to know whether the problem is in the device, the individual's use of the device, or the perception of the person and/or family regarding the usefulness and/or appearance of the device.

Inadequate training in use may be a factor in rejection of a device. Operational problems, environmental restrictions or prescription or construction errors may make the technology inappropriate or unusable by the disabled person. Although the physician may not be expert in the area of rehabilitation technology, it is certainly possible to ask the appropriate questions to elicit the concerns of the disabled person.

Finally, the physician who has genuine interest in the rehabilitation of his patients will be interested in encouraging and supporting the development of new rehabilitation technologies in response to the perceived needs of disabled persons. Lifelong dis-ability need not be synonymous with lifelong in-ability.

SUMMARY

Rehabilitation technology can expand the range and efficiency of function in disabled people. As a part of an ongoing rehabilitation plan, or for solutions to everyday problems in permanently disabled individuals, rehabilitation technology has a great deal to offer. Since physicians hold the key to access and payment for many technological aids, they must be willing to fulfill their role responsibly in obtaining these aids for those whose lives will be improved through such technology.

SAMPLE REQUIREMENTS FOR TECHNOLOGY (from MEDICARE BULLETIN, Feb. 1987, Chico, CA, p.18)

Prescription requirements for Durable Medical Equipment (reminder)

All claims for durable medical equipment (DME) must be accompanied by a physician's written prescription for the equipment. These prescriptions must contain:

- The patient's name, address and Medicare Health Insurance Claim (HIC) Number.
- A description of the equipment required.
- Complete written documentation of the medical necessity for any "delux", unusual or custom features.
- The patient's diagnosis and the symptom(s)/patient condition(s) which make the prescribed equipment a medical necessity.
- The patient's prognosis.
- The exact length of time the patient will require the equipment. Do not use "indefinite" as an indication of length of need. Prolonged need MUST be explained in months.
- The date on which the equipment became necessary.
- The prescribing physician's signature, printed name, address, state license number, signature and date.

Failure to provide the above information will delay claims processing and payment. For listings of documentation requirements specific to individual pieces of DME, see the alphabetical Bulletin indexes in this Bulletin (1986 articles) and in Medicare Bulletin No. 86-6 (September 1986, covering 1980-85 articles).

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Special Interest Group 7

Technology Transfer

Chair: Seldon Todd, Jr.

LINKING INDIVIDUALS TO EVALUATION OF REHABILITATION ISSUES

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ABSTRACT

Traditionally, evaluation in the rehabilitation engineering community has focused on technical analysis or clinical review of assistive devices. Evaluation processes, however, have not typically allowed the disabled consumer to play a participatory role. This paper describes a methods development project to focus evaluation and encourage active participation by disabled consumers and all elements critical to the process. A case study of an evaluation setting that directly involves a group of severely physically disabled young adults is presented.

INTRODUCTION

This paper focuses on a basic concern in the area of rehabilitation evaluation, that is the need for disabled people to become more closely linked to evaluation processes. To "link" individuals to a process simply means to establish a direct connnection or channel that enables communication between the contributing components. "Evaluation" is generally defined as a process by which the significance or value of something is determined by appraisal and analysis. In this case then, the evaluation link connects individuals to an appraisal process that determines the value or significance of a rehabilitation issue.

BACKGROUND

Evaluation is a recurring theme in rehabilitation, especially as it relates to testing the reliability of assistive devices, judging the effectiveness of service delivery programs, or assessing an individual's functional disability. Because evaluations of this nature affect disabled individuals directly and personally, it is common sensical that the views and perspectives of the affected individuals should be taken into explicit account (1). More typically, however, evaluation methods tend not to place those who are directly affected by the results in a participatory role (2).

Because the client is not directly linked to the process, a gap exists between the perceptions of the professional who evaluates and the disabled individual who must deal with the consequences of the evaluation. This gap prevails in most evaluation processes and may contribute to the problem of under-utilization of rehabilitation products and services by consumers.

In a recent report, Dr. Larry Scadden of the Electronic Industries Foundation indicated that the technology utilization problem is related to education and dissemination of information to end-users. "Companies have serious difficulty in disseminating product information directly to disabled individuals. Participation by the end-users in product selection will increase both demand and utilization of this technology. The inability to locate the potential market . . . places the burden of selection almost solely upon professional prescribers (3)."

Dr. Scadden's view of the client's "non-involvement" in product selection processes is complicated by an inherent cultural convention. Evaluation is a kind of ritual reserved for professionals; professional judgment is applied to the task of evaluation on behalf of the client. Clients may be involved in the decision-making process that subsequently results from evaluation, but not typically in the formulation or measurement of the process itself.

Under-utilization is also associated with the device or service that simply does not appropriately match the need and coping strategies of an individual. Again because the client is not directly linked to the process, the evaluation criteria used by the professional do not necessarily overlap the criteria used by the individual when he decides whether or not to use a product or service. It appears that evaluation methods can become over-specialized in directions that are not particularly relevant to meeting real-life needs. Scadden indicates that "these evaluations have emphasized [hardware] efficacy rather than user acceptance, an approach that could lead to the release of a product lacking commercial viability (4)."

To improve the prospect of product/service utilization and to respond to unmet needs, evaluation methods must begin to incorporate the measurement of how a product or service affects individual coping strategies and lifestyles. This measurement must be based on the direct perceptions and judgments of technology users.

DISCUSSION

Linking People To Evaluation

To test the hypothetical relationship between client involvement in evaluation and the utilization of products and services, empirical investigations aimed at linking people directly to evaluation processes are needed. SwRI-REC's efforts to develop client-based evaluation methods and to observe their impacts are described in the next section.

A basic strategy for measuring how a product/service affects individual lifestyles and responds to needs is to query users, to involve them directly in the process, and to take account of their assessments. Any approach for evaluating individual product/service effects (related to coping and lifestyle changes) requires the creation of special communication channels and a clear method for reporting and analyzing information. "Scaling" techniques are needed so that individual responses become commensurable "scores."

SwRI's approach has been to develop several settings that allow clients to participate directly in an evaluation process. These settings are supported by a set of resources. These resources include trained staff, procedures, software, and telecommunication capability. The software is based on the

SwRI-developed Value Assessment package (5) which enables systematic reporting and analyzing of "scores," as well as standard database and statistical software. This approach promotes communication through an interactive electronic network of evaluators, termed the LINK network.

Demonstration Project

The SwRI-REC is currently collaborating with San Antonio's Coalition for Independent Living (COIL) to test elements of the LINK approach to evaluation. As background, the membership of the COIL groups is comprised of approximately 15 congenitally and severely disabled young adults of normal intelligence. Formed in 1985, the organization's ultimate goal is to create an environment which will allow them to achieve maximum independence both individually and as a group. In addition, they plan to democratically and effectively manage their own facility.

Subsequent to several months of collaboration with the COIL group, a 5-stage project aimed at establishing elements of a LINK-based evaluation approach was outlined and approved by the group. Generally, the project focuses on the utilization of electronic technology to create a network of evaluators. In this case, the network and communication mechanisms have been created for the specific purpose of comprehensively evaluate the elements of an independent living environment. The project is currently in progress.

Stage 1

Eight severely physically disabled COIL members are currently involved in a series of five computer-assisted practice sessions to help develop decision-making and evaluation skills. Software and switches were developed to enable the members of the group (comprised primarily of non-verbal cerebral palsied individuals) to communicate opinions and independently select personal preferences related to a 1-week camping experience. A control group consisting of eight severely disabled individuals was also selected to participate in the study. These individuals will attend the summer camp, but will not be allowed to plan any portion of the camping experience. Pre- and post-questionnaires will be administered to both groups to determine benefits of participation in an evaluative process.

Stage 2

Enhanced computer hardware, software, and procedures will be used to present decision-making practice sessions in more realistic terms and to elicit elaborated views and independently considered judgments. Strategies for coping with realistic decision-making situations will be presented in a training setting. Evaluating choices in terms of cost and risk trade-offs will be emphasized with the group. Enhanced technology will allow the COIL members to participate in practice sessions by remotely dialing up the computerized sessions from their homes.

Stage 3

A COIL experimental group will use the enhanced "Link" technology to practice decision-making and evaluation skills that will be required as future residents and managers of an independent living facility. They will practice their decision-making skills on a computerized simulation model of situations that would be routinely encountered in an independent living setting. A control group will also be selected.

Stage 4

Using the LINK evaluation technology that has evolved throughout the process, the COIL organization will become involved in decision-making and architectural design specification for an independent living facility. The emphasis is on actual planning. Constraints imposed by budget, funding agencies, regulatory requirements, individual preferences and needs, siting and construction requirements, accessibility rquirements, etc. will be functionally decomposed for evaluation by the COIL members, families, care-providers, engineers, architects, etc. The LINK approach allows the definition and comparison of perspectives offered by several groups involved in a major evaluation/decision-making process.

Stage 5

A select group of COIL members will be instructed to operate the computer hardware and software independently. Conceivably, the COIL group could help other groups of disabled young adults to develop evaluation and decision-making skills to advance independence through evaluative networking.

Additional Applications

The SwRI-REC has begun investigations of additional applications of the LINK-based evaluation approach.

Cardiovascular Risk Patient Program

A specially designed cardiovascular risk modification program uniquely combines patient education with a patient-based evaluation process (6).

Cardiovascular risk patients monitor progress and evaluate individual performance by tracking "scores" on risk factors. The success of this program suggests the benefit of organizing networks of people who share a disability. Currently exploring possibilities for reporting and analysis of disability data, the SwRI-REC is analyzing individual cardiovascular risk modification data using the Link project's Value Assessment software. In a successive stage, the REC will investigate the feasibility of an evaluative network which would allow interaction with health professionals and conceivably serve as a continuing source of educational information and encouragement for cardiac patients.

Menninger Foundation

In preliminary planning meetings, the SwRI-REC has proposed that the LINK approach be used for experiments that test the efficacy of an evaluative network in relation to return-to-work problems.

Special Education Programs

The REC program has begun pilot work focusing on the evaluation of disabled students progress in special education programs. It is proposed that individual students and their families will monitor their performance and progress using specially-developed evaluation procedures and personal computer software.

CONCLUSIONS

The SwRI-REC was established to help deal with the issues associated with rehabilitation technology evaluation. Originally focusing on engineering evaluations and technical analysis of developmental rehabilitation products, the Center recently expanded its scope to also study more comprehensive approaches to evaluation systems. As indicated in this paper, the Center is exploring the potential and feasibility for client-based, self-assessment evaluation approaches.

ACKNOWLEDGEMENT

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A Portable Suction Device for a Tracheotomy Tube

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ABSTRACT

A patient with a permanent tracheotomy requires two concentric tubes or cannulas, to be placed in the opening to keep it clear. The inner cannula is removed for cleaning while the outer cannula is permanently fixed to the patient's windpipe. Mucus secretions must be suctioned from the outer cannula so that it does not become blocked. Suctioning is done approximately every three hours. This paper describes the development of a portable suction pump that can be used for the suctioning process.

INTRODUCTION

"A tracheostomy is an operation in which the windpipe is opened from the front of the neck so that air may obtain direct entrance into the lower air passages. The opening is made through the second and third rings of the trachea (windpipe)." (Thomson, p.901) This operation results in the condition of tracheotomy.

After the surgery is performed two concentric tubes, or cannula are placed in the opening to keep the passage clear. Figure 1 illustrates the placement of these tubes in the trachea.

Normally a person reflexively coughs up any secretions in the lungs, through the trachea, into the mouth where they are swallowed. In tracheotomy patients mucus secretions build up in the lungs and trachea because the passage from the lungs to the mouth is permanently blocked. These secretions must be removed.

When air flow through the inner and outer cannulas becomes restricted, by a build up of mucus, the cannulas must be cleaned. The inner cannula can be removed and cleaned quite easily. The outer cannula is fixed to the trachea and is more difficult to clean. The cleaning process begins with a saline solution being injected through the outer cannula into the trachea. This solution softens the mucus in the cannula and also causes reflexive coughing, which brings up mucus located in the lungs and lower trachea. The outer cannula is then cleaned with a suction device. The saline solution is repeatedly injected and the suction process repeated until the outer cannula and trachea are clear. The entire process takes about five minutes and must be done approximately every three hours.

At present a large electrical suction unit is kept at the patients home. If the tracheotomy patients leave his/her home for a period longer than three hours, it is necessary for the patient to have access to a portable suction device. The portable suction device presently used is the LAERDAL.

The LAERDAL suction unit consists of a dual piston suction pump driven by an electric motor. The pump consists of two cam driven pistons which operate 180 degrees out of phase. The motor which drives the cam is powered by a set of rechargeable batteries.This configuration works well but the entire package weighs about 4.5 kg (10 lb) and it is far to cumbersome for a small child to use as a portable unit. Therefore a smaller unit is desirable.

The object of this project is to design a small, portable, light weight, suction device for cleaning a tracheotomy tube. This device should be usable by small children as well as adults and should supply a relatively uniform suction and air flowrate.

DESIGN PROCESS

Assuming a person could without difficulty turn a hand crank at 70 rpm it was calculated that the pump should displace a volume of $2*10^{-5}$ m^3, giving it a theoretical flowrate equal to that of the LAERDAL, at 70 rpm.

Basing the design of the pump on this criterion, initially a 3 cylinder, doubleacting, crank driven piston pump was considered. This design however was dropped because it was felt that its overall size could be reduced and that the number of parts required was too large. Instead, a two cylinder pump with two double acting pistons driven by a cam and crank mechanism was considered.

The theoretical forces acting on the pump were then calculated, and parts such as cam size and crank length decided upon for a prototype pump with an aluminum cam. The remaining design of the pump was then carried out based upon available shop materials and cost. It was decided to build the majority of the prototypes parts from plexiglass. Figure 1 shows this prototype.

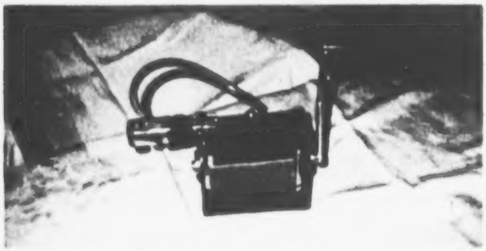

Figure 1- Prototype Design

Once the prototype was built, testing began so that its suction and flowrate capabilities could be measured. Initial testing showed that the pump performed well developing the necessary flowrate of 0.35 m^3/hr (12 ft^3/hr) at 70 rpm and a maximum suction of 65.7 kPa. It was felt that by adjusting the pumps clearance volume and reed valve stiffness these values could be improved. The pump was then modified and tested again. It was found that although its flowrate did not show an appreciable increase, the maximum suction it could provide increased from 65.7 kPa. to 77.6 kPa.

At this point permission was given by the medical community for testing of the pump on humans. A set of qualitative tests were carried out. Initially a 5 year old girl was used to test the pump's constraints because she was in the age group where more freedom of movement away from home is required. The tests were carried out with the pump in two positions, clamped to a table top and held between her knees.

When the pump was clamped to the table the subject had no difficulty in cranking it under zero suction conditions and only a small amount of difficulty under blocked flow or maximum suction conditions. On the other hand, the subject had problems with the length of the handle when the pump was held between her knees. This was due to her small size. The difficulty increased when she was required to crank the pump under blocked flow conditions. Thus the need for a better method of fastening the pump between a persons knees became apparent. It was decided to use a pair of velcro belts wrapped around each leg and then fastened to the pump to alleviate this problem. Figure 2 shows this modification.

Overall the prototype is capable of exceeding the LAERDAL's maximum flowrate of .423 m^3/hr. This flowrate was reached at 75 rpm of the prototype while the LAERDAL's low setting flowrate of .314 m^3/hr was reached at 55 rpm.

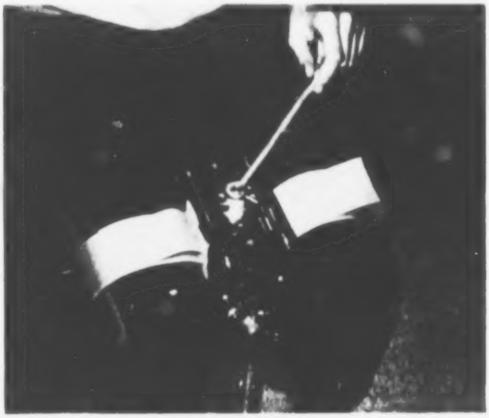

Figure 2- Further Prototype Modifications

It was concluded at this point that the prototype was indeed a good solution to the design problem along the lines of size and obtainable flowrates. Calculations were then done taking into account weight, material and material cost for a final design. The materials compared were magnesium, aluminum and nylon. Estimated pump weight and cost of materials are as follows; aluminum, 2.78 kg, $4.00; magnesium, 1.9 kg, $4.50; nylon, 1.2 kg, $6.00. The other major factor considered was the materials resistance to corrosion.

Basing the material selection upon these factors it was decided that even though the nylon cost $2.00 more per unit it was worth the extra cost because of the weight saving.

At this point a set of drawings of a final pump design of nylon were made and an investigation into production costs was made . It was found that.to have the pump manufactured by manual means the cost would be approximately $709.00/pump. For a production of greater than 10 pumps, manufacture by CNC machines would result in a cost of approximately $123.00 per pump. Manufacture by injection moulding would not be feasible for a run of under 1000 pumps. A run of 1000 pumps would result in a cost of approximately $227/pump. This is due to the large initial cost of the dies required. After the initial run of 1000, a second run of 1000 would result in a cost of approximately $ 27.00/pump.

The hand pump can also be driven by a variable speed electric drill. This has two advantages. The first advantage is that with the electric drill powering the pump, the patient has both hands free for other tasks. The second advantage is that in this configuration the pump can also be used to replace a second more permanent unit, which costs about $350.00, and which every tracheostomy patients needs.

CONCLUSION

The major conclusion to be drawn from this project is that it is possible to improve on the present design solution, the LAERDAL. The hand pump proved to be a feasible solution to the design problem. It is capable of exceeding the LAERDAL's flowrate and suction capability. Also at a cost of $123.00/pump for CNC produced, or as little as $54.00/pump for injection moulded, its cost would be well under the LAERDAL's cost of $630.00/unit.

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NATIONAL SURVEY OF REHABILITATION TECHNOLOGY UTILIZATION IN STATE VOCATIONAL REHABILITATION AGENCIES

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ABSTRACT

The use of rehabilitation technology services within the state/federal Vocational Rehabilitation Program has reportedly increased during the past ten years. There is however a lack of information which documents the extent of this utilization or descriptions of how services are being delivered. This study was part of the 13th Institute on Rehabilitation Issues (IRI) which focused on rehabilitation technologies. Information gathered describes personnel and staffing patterns, use of consultants, rehabilitation technology service areas, service delivery methods, sources of funding and identifies critical needs.

INTRODUCTION

The use of rehabilitation technology services within the state/federal vocational rehabilitation program has increased rapidly during the past ten years. Frequent reference to rehabilitation engineering, the use of rehabilitation technology resources, and specific mandate for this service in the 1986 Vocational Rehabilitation Act, emphasize the growing awareness of the potential impact of rehabilitation technology(3).

There is, however, a lack of information which describes how rehabilitation technology resources and services are utilized in present vocational rehabilitation programming. Relatively little has been written about the use of rehabilitation technology in the vocational rehabilitation process. Survey information describing current activity has been particularly limited.

An important aspect of the investigation of technology applications in rehabilitation is to identify how the various state VR programs are using technology. With limited information on the use and application of rehabilitation technology available, the identification of current service delivery practices and use of rehabilitation technology should be beneficial for both expanding and improving these services.

This study was conducted as part of the Institute for Rehabilitation Issues (IRI) Study Group on "Rehabilitation Technologies". The IRI Study Group identified the state/federal Vocational Rehabilitation program as the primary target for the study of rehabilitation technology. Consequently, a national survey was designed and conducted to obtain specific information on the current use of technology(2).

METHOD

The primary target audience for this survey included both general and blind State Vocational Rehabilitation agencies. Questionnaires were sent to all general, blind and combined agencies on the Council of State Administrator of Vocational Rehabilitation mailing list. Included in this sample were trust territories and other agencies, however only agencies from the fifty states and the District of Columbia were included in the final analysis. Following the initial mailing a follow-up letter and survey questionnaire were sent to those agencies not responding. A total of 60 responses were received for a response rate of 72%. This response accounts for input from either general, blind or combined agencies from 48 of the 50 states.

The rate of response from general agencies was highest with 84% submitting information. Information was received from 60% of blind VR agencies, however this response may be misleading since some of these agencies may have been reported under the "general" category for that particular state.

This questionnaire was designed to obtain both descriptive data as well as more general information. A request was made for materials describing their use of rehabilitation technology along with several open ended questions to solicit comments.

RESULTS

Personnel and staffing patterns

Most important in the delivery of rehabilitation technology services are the staff that are involved. This includes not only specialized staff such as rehabilitation engineers and rehabilitation technology specialists, but all staff that work as a team to make effective use of technology to meet the needs of persons with disabilities. Questions were asked related to the type, number and responsibilities of staff involved in the delivery of services.

Most of the VR agencies reporting indicated that they utilize their own staff to deliver rehabilitation technology services. Sixty six percent of general agencies (29 states) used this approach while almost 79% of blind agencies used their own staff (12 states). Rehabilitation counselors were cited as the most frequently designated staff in blind (58%) and general agencies (41%). Following rehabilitation counselors were job placement specialists (33% blind, 24% general) and vocational evaluators (17% blind and general). Eight blind agencies also reported that they utilize "rehabilitation teachers" to deliver rehabilitation technology services.

378

The number of full time equivalent (FTE) rehabilitation counseling staff who were designated for delivering rehabilitation technology services varied significantly. Of the total of 41 agencies responding to this question, 22 indicated rehabilitation counselors did not deliver rehabilitation technology services. The remaining 19 reported that from one to 163 counselors provided these services. This excessive variation makes it difficult to draw any clear conclusions. These findings suggest that a large portion of rehabilitation technology services that are provided may be delivered by staff with little or no technical background.

An exception to this is the use of rehabilitation engineers which was reported for 22% of all agencies. These staff, along with rehabilitation technology specialists and adaptive equipment specialists, reportedly used by 17% of those agencies, represent a group of professionals with specific training in the use and application of rehabilitation technology. Analysis of this data however is somewhat disappointing. Although 22% of the agencies reported use of a rehabilitation engineer on staff (nine agencies), this amounted to only a total of ten FTE positions. Rehabilitation technology specialist utilization was even more limited with seven agencies reporting a total of eight positions.

Other agency staff that were cited as being used to deliver rehabilitation technology services included orientation and mobility specialists, rehabilitation teachers, orthotists, optometrists, information specialists, architects, electrical engineers, carpenters/plumbers, and independent living specialists. This wide variety of staff disciplines and backgrounds emphasizes the diversity and scope of rehabilitation technology.

Use of consultants

Consultants for rehabilitation technology services are commonly used in almost all agencies (85%). A wide variety of job titles for consultants were cited. The most frequent consultants reported by general agencies were rehabilitation engineers (70%), occupational therapists (73%) and physical therapists (70%).

Blind agencies overall tended to hire far fewer consultants. Rehabilitation engineers and vocational evaluators (38%) and physical therapists and work adjustment specialists (25%) were identified as the most frequently used consultants.

Other consultants employed by various agencies included electrical engineers, manufacturer's representatives, low vision specialists, homemaker and staff from specialized centers.

Rehabilitation technology service areas

The areas of application for rehabilitation technology services tended to closely follow the philosophy and objectives of the state/federal VR program. Vocational (98%), educational (72%) and independent living (70%) were the most frequently cited areas where rehabilitation technology was used.

Services provided directly by VR agency staff tended to include recommendations of devices or modifications and contracting with vendors for fabrication (90%) along with assessment of functional capacities (88%). The capability to do actual fabrication and modifications within most state agencies appeared to be limited. Communication services (90%), computer applications (88%) and sensory aids (86%) were the most frequently purchased services/equipment for both general and blind agencies. Transportation/vehicle modification was another significant area for general VR agencies with 95% purchasing services and products in this area.

Service delivery methods

The approaches used to deliver rehabilitation technology services varied greatly between agencies. It is interesting to note that "contracting with private vendors" is used by 78% of the general VR agencies. In addition, this is followed by "utilizing vocational rehabilitation program field office staff (58%) and medical equipment dealers" (56%). Despite a trend toward designating specific agency staff as "specialists" to deliver rehabilitation technology services, private vendors and general VR staff play a very key role in the actual provision of services. Blind agencies tend to rely even more on their own field staff (67%) followed by contracting with private vendors (47%) and then utilization of a centralized rehabilitation technology resource center (40%).

Six states (11%) of the agencies reporting, indicated that they utilize mobile rehabilitation technology services. A larger percentage (29%) report that they utilize a single centralized rehabilitation technology resource center.

The use of "Regional Resource Centers" to deliver rehabilitation technology services was surprisingly low. Only three states reporting indicated that regional centers were utilized. This would appear to be due to a lack of large facilities or resource centers that are designed to deliver comprehensive technology services. Centralized rehabilitation technology resource centers were more frequently cited as service delivery approaches. Blind agencies indicate that 40% or approximately seven states maintain some type of single, comprehensive center. General agencies report somewhat less utilization of this approach with 29% or about 12 states operating with this as a primary delivery model.

Responses from the various agencies indicated that a combination of approaches were almost always utilized. State agencies with the most comprehensive programs tended to employ several of the service delivery methods discussed.

Sources of funding

Funding for rehabilitation technology services and for purchase of equipment come primarily from regular counselor case service budgets in all VR agencies (100%). Other sources of funds most frequently used included client/family support, employer, worker compensation, insurance, Medicare/Medicaid and philanthropic/service groups. The use of a separate "technology fund" to supplement individual counselor case service budgets was reported in several states. In reporting critical needs, funding and financial assistance was the second most frequent need identified. Rehabilitation technology services appear to be seriously lacking in the amount of tracking of expenditures that occurs. Only 27% of agencies surveyed (24% general, 36% blind) report they provide special tracking of expenditures for rehabilitation technology services.

Critical needs

The needs identified by VR agencies as most critical in their application and use of rehabilitation technology are summarized below. Statements have been clustered together and are rank ordered by the number of respondents. This survey item was open ended and should be a good indicator of needs in the rehabilitation technology area as perceived by agency administrators.

1. Need for training of VR staff on rehabilitation technology
2. Funding, financial assistance for services/purchase of aids and devices
3. Staff to function as rehab technology specialists, rehab engineers, etc.
4. Availability of comprehensive information resource center
5. Expansion of rehab technology services available, particularly in rural areas
6. Availability of low cost aids/devices

CONCLUSIONS

Overall, survey results identified more service delivery activity in place than previously expected. Several states have developed programs that utilize some combination of rehabilitation engineers or rehabilitation technology specialists working with vocational rehabilitation field staff. These states use a variety of models ranging from: an established network of four regional rehabilitation engineering centers in VR field offices; a combination of facility based rehabilitation engineering and mobile rehabilitation technology services; rehabilitation technology specialists serving as support staff to regional VR field staff; and centralized rehabilitation technology resource centers.

The reliance on VR field office staff to deliver a large portion of rehabilitation technology services was common in most of the states reporting. This approach places a great deal of responsibility on individuals that in most cases have had little or no training for this task. Undoubtedly, the VR field staff must play a central role in the appropriate and effective utilization of technology. However, the practicality of training VR counselors as the primary providers of rehabilitation technology services is questionable. In addition, the ability of any one individual to meet all of the rehabilitation technology needs of a VR agency is also unrealistic. The need for trained personnel and multidisciplinary technology teams is becoming more and more evident.

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BEYOND VELCRO™: A STUDENT PROJECT IN HUMAN FACTORS AND DESIGN FOR PEOPLE WITH SPECIAL NEEDS

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ABSTRACT

The Veterans Administration is currently investigating the use of Computer-Aided Design and Manufacturing (CADAM) technology to address the unique clothing and dressing needs of people with physical disabilities. Part of this effort requires a redefinition of the state of the art in garment closure through the evaluation of existing fasteners and the development of new fastener technology. Given the necessary emphasis on human factors in designing for people with special needs, a project that focused on innovative fasteners seemed an ideal educational opportunity for upper division design students. Subsequently, a project bid was submitted to Professor William Moggridge, and accepted for use in his course 'Product Design and Human Factors' in the Mechanical Engineering department at Stanford University.

This paper will discuss this design project and how it fits into the overall research objectives of the larger VA design-development project entitled *Computer-Aided Clothing Design for People with Special Needs* (also known as 'CAD-Clad'). The most notable results of the students' efforts will be presented as well.

INTRODUCTION

In 1985, the Office of Technology Assessment published the results of a study titled *Technology and Aging in America* that focused on the functional status of the elderly and ways in which technology can assist them to maintain their independence and enhance their quality of life. Among the research priorities established by the assessment team was the development of assistive devices and rehabilitation techniques for elderly individuals, particularly those with multiple impairments. These research priorities are driven in part by the current economics of health care and the forecasted increase in the elderly population that will affect the prevalence of chronic illness and functional dependency in our society.

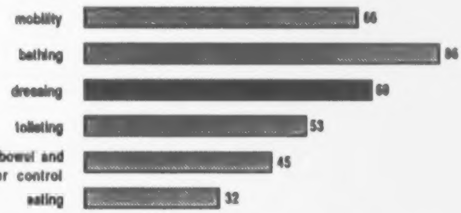

Figure 1. Percent of nursing home residents who need assistance with basic physical activities: United States, 1977 (1).

Typically represented among chronic illnesses in the elderly population are arthritis, multiple sclerosis and functional limitations caused by the occurence of a stroke. It is important to note, however, that arthritis affects people of all ages. Presently 36 million people have some form of arthritis; of these, 7 million have rheumatoid arthritis which directly affects the joints of the hands and feet (2). Add to this the number approximately 6,000 cases of spinal cord injury that result in paraplegia and quadraplegia per year (3) along with the new cases of multiple sclerosis and a variety of other disabling conditions, and the total number of people who could benefit from advances in garment technology increases dramatically.

The significance of this research, even at the level of a student project, lies in the fact that dependency in dressing is one of the three characteristics that are the strongest predictors of future residency in a nursing home (1). Well-designed, well-placed and well-configured fasteners, as features of accessible, appropriate clothing, can be used as assistive devices. Not only do they have the potential to increase the level of autonomy in a very necessary activity of daily living, but they also can contribute to the quality of life of people with hand and arm limitations by encouraging greater involvement of individuals in their own health maintenance and decreasing their need for assistance from others.

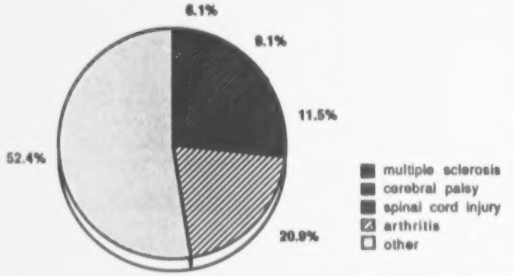

Figure 2. Many clothing- and dressing-related problems involve joint manipulation. This graph shows the breakdown of disabling conditions that influence an individual's ability to dress (4).

BACKGROUND

CAD-Clad

CAD-Clad is a new project at the Palo Alto VA Rehabilitation R&D Center that grew out of: 1) a demonstrated need for accessible daywear for people in long term care facilities; and, 2) wishful thinking for a computer-based pattern system that would allow one to enter basic body measurements, designate problem areas, select clothing features, press a button and receive a custom pattern. The intent of this project is to begin work toward a general solution to the highly individual fitting, dressing and functional clothing requirements of people with disabilities. It is believed that computer-aided design technology will provide the tools to create accurate graphic and digital representations of the human body and to allow critical dimensions to be manipulated to produce a custom-fit and designed pattern.

Beyond Velcro™

The student project was entitled **Beyond Velcro™** for several reasons. While Velcro™ is the current favorite of occupational therapists, physical therapists, and people whose disabilities make independent dressing difficult (minimal pressure is required to join two pieces and garment closure can occur without precise matching of the fastener), it has characteristics that make it a less than optimal garment fastener. While it can be used to provide a strong, unbroken closure and a tight silhouette like a zipper, it is not as flexible nor does it allow for butt-joints-- there must be fabric overlap for closure. If used in place of buttons, it changes the draping, or line, of the garment and, if not matched properly it has the potential to abrade the skin and cause pressure sores even as it is working to keep the garment together. Finally repeated laundering drastically reduces the life of the Velcro™ especially if the two halves are not joined together beforehand.

PROJECT DESCRIPTION

The students were required to design a fastener that would enable an individual with decreased manipulation capabilities and limited range of motion in the upper torso to dress independently. Design criteria were determined by use of the matrix according to user group, fastener and desired application (see Figure 3). Characteristics and definitions were given for each of the categories in the matrix (see Table 1). For example, a student who chose to design a zipper for a client with amyotrophic lateral sclerosis (ALS) who wished to access the contents of her purse without aid, would find that: 1) a zipper is defined as a 'continuous fastener that does not require a cloth overlap and allows for a tight silhouette'; and, 2) a person with ALS may have minimal strength between the fingers and accompanying weakness in the arms and hands.

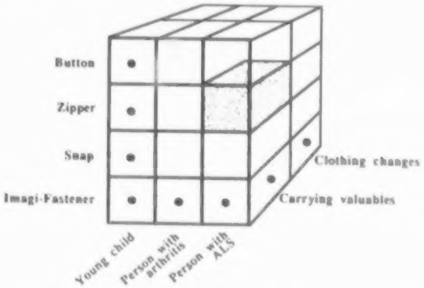

Figure 3. User, fastener and application design matrix.

Other design considerations included the psychosocial and functional aspects of clothing as well as how the fastener was to be integrated into the garment. In addition, it was required that the design be machine washable, and retain its integrity with repeated washing, allow for easy on/off manipulation of the garment, be capable of mass production and not require the services of a second pair of hands. Designs could be reminiscent of past fastener technology, build on existing fastener technology, or simulate future fastener technology.

Beyond Velcro™ was deemed an appropriate project for this class in that it demanded abstract thought in terms of human factors in requiring the students to design everyday devices for unfamiliar situations and look beyond their own experiences to design for others. Other design projects in the framework used by Professor Moggridge include: large scale, fashion driven design; the design of a user interface (requiring that students think about how controls work and how people work with controls); and, small scale, mass production design.

RESULTS

The students' work was evaluated with respect to: analysis and problem solving; aesthetics and subjective values; execution of two dimensional work; and, execution of three dimensional work. Critique was given by a panel of jurers whose members were chosen by virtue of their real life experiences with a disability and/or their expertise in a given field.

Student designs ranged from the futuristic (far-out but not beyond imagination) to the fundamental. (Many caused the panel of judges to wonder why such fasteners did not exist already.)

A visionary solution was found in a flexible, magnetic strip fastener that was zipper-like in design. This fastener was self-aligning, maintained a tight silhouette and required minimal pressure to achieve closure (see Figure 4). The best feature was a hand held wand that temporarily demagnetized the fastener and allowed the garment to be removed with ease. The jury expressed concern about how one would wash a garment with magnetic fasteners given the metal components in a washing machine and what precautions would be necessary to protect items such as floppy disks.

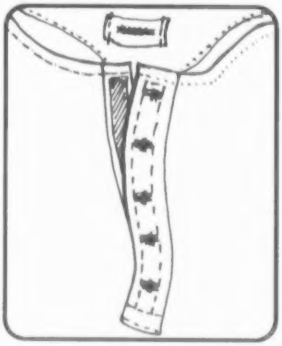

Figure 4. Magnetic strip fastener.

User/Disability: Characteristics and Notes

1. **A very young child** (2-4 years old)
   - Limited dexterity (fat crayons vs. thin) and strength are considerations.
   - Size is a factor in terms of ease in fastening.
   - Matching fasteners, or joining two things together (like a separating zipper), may cause difficulties.
2. **Josephine Q. Lefthanded or Giuseppe P. Righthanded/Arthritis**
   - Arthritis is joint-related (e.g., degradation or inflammation of the tissue between the joints); it can be very painful.
   - The condition may be worst in the morning. Morning is the time when people most need dextrous hands and fingers for dressing.
   - Arthritis is the leading crippler of young adults; it is not an age-specific disease.
3. **Rhoda Neima, juror/ALS (amytrophic lateral sclerosis)**
   - ALS is a degenerative muscular disorder that is characterized by weakness. It is similar to arthritis, without the element of pain.
   - Our client has minimal strength between her fingers, and accompanying weakness in her arms and hands.
   - She would like to be able to dress her children more quickly and easily. Traditional fasteners on children's clothing are inappropriate for her needs. She has had someone add velcro to much of her children's clothing, but has not always been pleased with the results.

Applications:

1. **Carrying valuables**
   - What valuables might each of these people carry? (Examples range from toys to briefcases.)
2. **Clothing changes**
   - Consider how clothing must be manipulated in the different situations a person might encounter in the course of a day (from dressing in the morning and undressing in the evening to going to the bathroom and changing clothes in gym class).
   - Remember that morning dressing can be difficult for those with arthritis.

Fasteners:

1. **Button**
   - Buttons can be defined as discrete fasteners that pass through clothing and perform like a stop gap.
   - Buttons are not always circular.
   - A button's strength is in its attachment to the clothing and the size of the buttonhole.
2. **Zipper**
   - A zipper is a very strong continuous fastener that does not require a cloth overlap and allows for butt-joints and a tight silhouette.
   - Failure occurs if a tooth breaks or if a foreign object gets into the zipper causing it to jam.

Table 1: User characteristics and fastener and application definitions.

Playful, but practical, solutions included a two-part, color-coded fastener that joined like a cap to a pen (see Figure 5), and colorful wooden balls on cord that were pushed through an eyelet reinforced with neoprene to close a beach bag. The jurers with experience in dressing children and/or teaching children to dress found the 'pen cap' solution particularly delightful and appropriate to the needs of small children. The designer was commended for her use of auditory and tactile feedback, color-coding and appropriate size in designing a fastener for children's clothing.

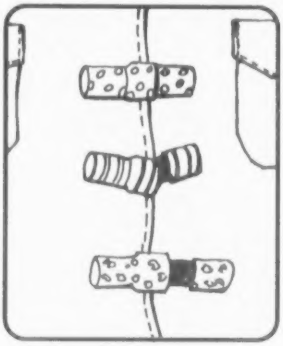

Figure 5. The 'pen-cap' solution.

Fundamental solutions often involved retrofitting existing fasteners and adding additional components to an existing fastening system (e.g., buttons on a dress shirt) to facilitate dressing. Some were especially innovative in that they applied technology used by industries other than the textile and apparel industries.

CONCLUSIONS

While this project may have done nothing to make appropriate fasteners available to people with hand and arm limitations, it may have opened the door to an area of design to which many students were previously unaware. The project will have been a success if one student in ten has a new appreciation for good design and meeting human needs.

ACKNOWLEDGEMENTS

The author would like to thank Rhoda Neims and Kay Holloway for their expertise as jurors, Kate Oliver for her efforts in researching past and present fastener technology, and the students of Product Design and Human Factors, Fall 1986.

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BENDING STIFFNESS OF BACKBOARDS FOR ACUTE SPINAL INJURY PATIENT TRANSPORT

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ABSTRACT

Apparatus for moving an acute SCI patient must satisfy the dimensional, strength and lightness constraints of ground and air transport, and the need for X-ray transparency for diagnosis, without compromising stability of the spine. Although backboards of various designs and materials are in common use for extrication and immobilization of SCI victims, there exist few if any published data on their mechanical properties. This paper reports on comparative stiffness (defined as product of modulus of elasticity and moment of inertia) of several commercial and experimental backboards under end-supported center-loaded bending. Given a simplified set of assumptions as to impact of bending curvature on displacement of a cervical fracture, it was found that fabric stretchers are, as expected, unsuitable for SCI patients, and one commercial backboard is marginal under worst-case conditions.

INTRODUCTION

This project is part of a program to improve treatment of spinal cord injury (SCI) patients during the earliest phase of rehabilitation: from the time that SCI occurs through transport to a specialized spinal center, and whenever the patient must be moved for therapeutic or diagnostic procedures. The platform—stretcher, backboard or bed—upon which the SCI patient is placed must prevent motion of the spine in any direction at the site of injury. This paper describes an experimental study to determine whether bending of various types of backboards might contribute to undesireable flexion of the spine.

BACKGROUND

Since extrication from an accident site and transport to an emergency hospital is commonly performed with the presumed cervical SCI patient immobilized on a short spine board, efficacy of this method was compared and found superior to various cervical collars by radiography of volunteer subjects by Podolsky *et al* (1); however, no tests of the restraints alone were performed. A comprehensive review of the history and currently available varieties of full-length spine boards from the point of view of the emergency medical technician was made by Dick and Land (2) without reference to stiffness or X-ray compatibility.

Possible inadequacy of existing SCI patient transport equipment was investigated by Connolly (3), with the qualitative note that the Stryker frame cot used in Collins traction had measureable sag under load. This discovery and known difficulty of adapting existing equipment for computerized tomography (CT) prompted design of three prototype stabilization/transport systems, one made of laminated wood (4), one of fiberglass over a thick variable-contour foam core (5), and one of orthogonal carbon-fiber/epoxy skins over a curved constant-thickness foam core (6).

The third backboard/traction system has been in clinical use by Santa Clara Valley Medical Center (SCVMC) and Stanford University/SCVMC Life-Flight since February, 1985 (7). In addition to cervical and other spinal injuries, the backboard was put to unforeseen use in helicopter transport of pediatric patients, one patient having bilateral arm injuries, and evacuation from the scene of injury, rather than from an emergency hospital.

According to Edwards, *et al* (8), CT scan of lower spine injuries shows that canal area is typically constricted to 52% of normal; surgical realignment may restore it to 83% but with little effect on neurological outcome for improvement beyond 66% of normal. In the cervical spine (C-5) the canal can be modeled as an isosceles triangle of 25 mm base and 15 mm height; if 50% of the area is occluded, each additional 0.042 mm of vertebral misalignment in the antero-posterior direction reduces the area by 1%. If 5% additional loss of area is considered significant, then transverse motion of the vertebrae at the injury site must be less that 0.517 mm, which corresponds to about 2.5° flexion over the 1.2 cm height of one vertebra .

METHODS AND MATERIALS

Each backboard was full-length (typically 18 x 72 inches) and was measured with two free spans: maximum and constant section length. Boards were placed on 1/2 inch diameter rollers on a steel surface plate; to distribute local stresses, 1/4 x 6 x 8 inch aluminum plates were placed between rollers and the underside of the board. Five Starrett 2-inch-stroke dial indicators were mounted 4 to 6 inches in from one edge toward the center line, spaced 12 inches apart [Figure 1]. Weights (either 12 inch diameter cast iron plates or 4 x 6 inch lead bricks) of 25 lb mass were stacked at the center point of the board. Indicator readings were recorded typically twice at 15 and 30 seconds after applying or removing each weight.

The backboards tested to date are: [1] a prototype board consisting of orthogonal carbon fiber/epoxy skins over 12 mm "Klegecell" PVC foam core with constant-thickness cylindrical geometry of 30 inch radius (6), [2] a "Dixie 2001" board of 1/16 inch unreinforced thermoformed ABS skins over 1.5 inch foam core with trapezoidal cross-section and 1-inch diameter grooves in the underside, [3] a standard ambulance spine board of 3/4-inch hardwood plywood having two 3/4 inch square ribs on the underside, [4] an experimental fiberglass board (5), and [5] a commercial aluminum tube/fabric covered stretcher hinged at the center (Ferno-Washington #12). These differed considerably in cross-section depth and area, and hence in moment of inertia [Figure 2].

RESULTS

Deflection contour resulting from 200 lb. load at midspan of the constant-width segment of all boards tested is given in Figure 3. Representative change in contour with increasing load on the constant-width segment is shown in Figure 4 for the carbon-fiber composite board. Comparisons of stiffness to weight ratio, calculated deflection under distributed 200 lb load and linearized angle due to that deflection are tabulated in Figure 5.

Both the "Dixie" and the carbon fiber boards had nonuniform tapering section width for the foot 24-27 inches, and the latter had reduced constant 10-inch width for the head 16 inches. Thus, maximum span measurements do not yield constant deflection gradients for these examples. Mean angle when center loaded with 100 lb over the full span was 2.5° for the Dixie board; for the carbon fiber board it was 1.7°.

In constant-width bending, the experimental fiberglass board had the greatest stiffness (**EI** product), due to its relatively thick skins and deep section. Second stiffest was the plywood board, in part because of the significant contribution of the oak ribs to its moment of inertia. The carbon fiber composite board was about half as stiff as the fiberglass board, 66% stiffer than the aluminum tube stretcher and 2.4 times stiffer than the "Dixie 2001". These values are based on simple beam theory, and may differ by several percent from actual stiffness due to the high width-to-span ratio.

The "Dixie" board had measureable viscoelastic lag in reaching a stable deflection after applying or removing load; 0.1 mm variation between 15 and 30 sec readings at center span was typical. Separation of the thermoplastic skins from the foam core is a possible contributing factor. Such effects were not measurable in other specimens except for the fiberglass board at 200 lb load (0.01 mm).

DISCUSSION

Actual impact of bending of a backboard on the spinal stability and potential neurological recovery of a SCI patient depends on restraint of the head against lateral and torsional rotation, which may be mechanically coupled to bending deflection, and to the degree of compression of the spinal cord in its canal, which may be increased by further flexion of the neck (**8**). If the model described above is reasonably accurate, 2.5° flexion is the safe uppre limit. By calculation from short-span measurements, this limit is not met by the Dixie and Ferno-Washington devices (the latter is not intended for SCI patients) under the worst-case conditions of a 200 lb distributed load supported by the extreme ends. However, the Dixie board deflected to just under 2.5° when a 100 lb concentrated load, producing the same maximum bending moment as a 200 lb distributed load, was supported by the ends.

The carbon fiber board has more than twice the stiffness and three times the stiffness-to-weight ratio of the Dixie board, due to a high moment of inertia for its thickness as a result of the cylindrical section and to the intrinsic stiffness of the composite skins (elastic modulus calculated to be 464 kps for 5/8-inch thickness) (**9**). The deflection profiles [Figure 4] show deviation from the curve of a rectangular cross-section beam, due to the off-center placement of the dial indicators, which detect flattening of the cylindrical section near the load point and reduced radius elsewhere. Despite poorer stiffness, the Dixie board is an acceptable device, in that it has comparable cost, better X-ray transparency and lower weight than wood boards. If it becomes possible to manufacture carbon fiber composites at much reduced cost, this material would yield a superior product.

ACKNOWLEDGEMENTS

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Figure 1: BENDING TEST APPARATUS

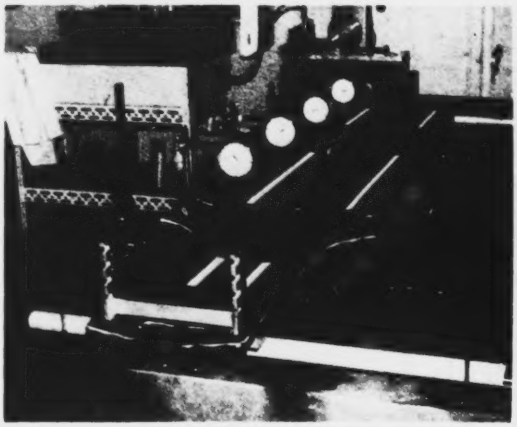
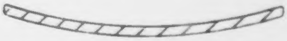
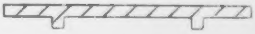


Figure 2: BACKBOARD CROSS-SECTIONS

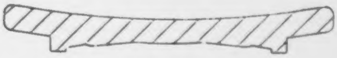
Carbon Fiber Composite



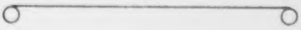
Plywood



Fiberglass



Aluminum tube (F-W #12)



"Dixie 2001"

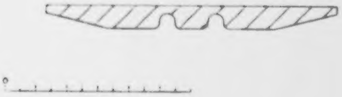


Figure 3: CONSTANT-WIDTH DEFLECTION, concentrated 200 lb load

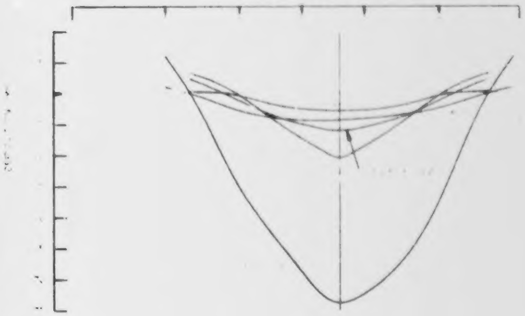


Figure 4: DEFLECTION WITH INCREASING LOAD; CARBON FIBER COMPOSITE BOARD

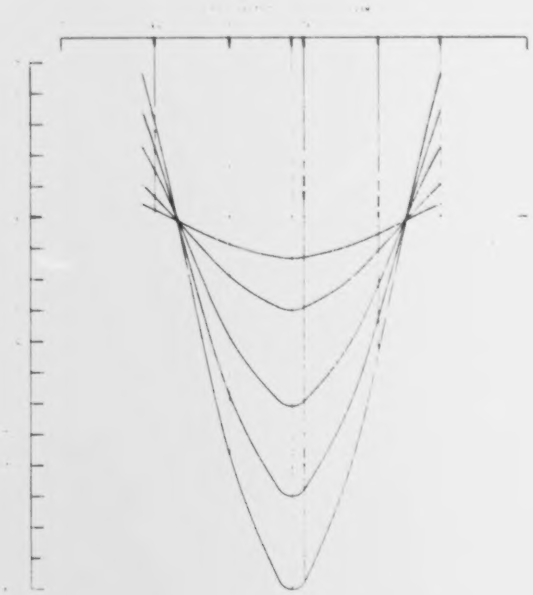


Figure 5: COMPARATIVE RESULTS, 200 lb LOAD

Specimen:	Wood	Dixie	F-glass	C-fiber	F-W #12
Span, in.:	48	48	36	36	36
Deflection, mm.:	8.83	33.76	2.80	5.93	9.86
EI, lb-in^{2}x10^3:	1326	347	1766	833	501
Weight, lb.:	21	13.7	25.9	10.4	7.8
EI/weight, in^{2}x10^3:	63.1	25.3	68.2	80.1	64.2
Cost, $:	95	140	1500	1345	95
FULL SPAN CALCULATION, DISTRIBUTED LOAD:					
Deflection, in.:	.73	2.80	.55	1.17	1.94
Linear Angle, deg.:	1.2	4.5	.9	1.9	3.1

COMPOSITE MATERIALS FOR REHABILITATION DEVICES

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ABSTRACT

Composite materials have very good strength and stiffness to weight ratios. These properties offer advantages of better mobility and less energy consumption for users. A variety of materials and manufacturing methods exist. Low cost and easily implemented methods of manufacturing and design are discussed.

INTRODUCTION

Composite materials is currently an active area of research and development. However, the advantages of composite structures have been recognized for a long time. Adobe bricks, the Damascus sword and many wooden structures took advantage of composite fabrication. The human body consists of composite structures on many levels. On a microscopic level everything can be considered to be a composite. This is not a practical concept, however. A useful definition would be one which identifies those structures which are synthesized or analyzed using the mathematical or mechanics concepts of composite theory. A useful distinction is between composite structures (e.g. Damascus sword) and composite materials (e.g. adobe bricks). In composite materials there is usually a continuous phase and one or more discontinuous phases. Another useful classification is between those materials in which the discontinuous phase is there to reinforce the continuous phase (fiber reinforced metals, dental composites) and those materials in which the discontinuous phase is the most important property and the continuous phase is there to hold the discontinuous phases together (fiber reinforced plastics). The discontinuous phases of man-made materials come in many forms: fibers, flakes, particles, sheets, etc. Properties of the composite are varied by changing the distribution, the orientation, the volume percent, and the properties of the phases. Interesting and useful engineering materials and structures can thus be built. But, what do composite materials have to offer rehabilitation devices? Composite material usage in assistive devices will reduce the specific energy consumption of users and thus elevate their comfort level and increase their independence. Only a few examples of assistive devices made of composite materials exist because composite materials are perceived to be hard to design and costly and difficult to manufacture. This paper reviews manufacturing methods and materials selections which are appropriate for low cost rehabilitation devices.

BACKGROUND

The impetus behind composite materials development in the aerospace industry has been the specific modulus (E/ρ) and specific strength (σ/ρ) of high performance composites. This is also important in many rehabilitation device applications. Elastic properties of composites can be controlled. The elastic properties of adjacent body segments can be matched more readily. Modulus gradients in a material can reduce stress concentration factors in transition regions. Composite materials can be designed to retain structural integrity after the first failure has occurred. Assistive devices which are used during X-Ray examinations benefit from radiolucency. Polymer composite structures can be molded into shapes which fit the complex geometrical configurations of body parts more easily than machined parts. These are only a few examples of the opportunities which are offered by the myriad of combinations and permutations existing in composite material structures. Simple manufacturing and design methods are needed for widespread use of composites in rehabilitation engineering.

There are two main types of composites that will be considered. They are thermoset and thermoplastic. It is important to investigate methods transfering high tech, high cost manufacturing methods for composite materials to low cost, low tech methods of processing that can be used to develop prototypes and production parts. The scope of the paper deals with selections of materials and processes that can be used with miminal training and experience.

MATERIALS

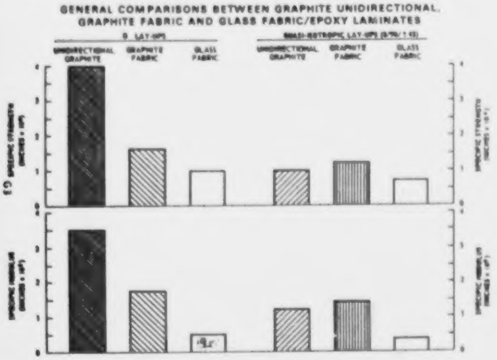
The three major types of fiber reinforcement for polymers are glass, graphite and aramid (Kevlar). Glass fibers are very strong however their elastic stiffness is much less than graphite or Kevlar fibers, however they are significantly stiffer than the resins they reinforce. Glass is slightly heavier than graphite. Glass is also the most inexpensive fiber, see Table 4. Graphite fibers can be obtained in a number of different stiffnesses and strengths. Table 2 compares some of the properties of typical fibers. Graphite is the lightest of the fibers and the stiffest and usually the most expensive. The stiffness of Kevlar fibers is in between that of glass and graphite. Kevlar fibers are very tough and are resistant to many hostile environments. These fibers have the lowest compressive strength, however. Figures 1 and 2 show the major advantage of composite materials - specific modulus and specific strength. These are defined as the strength per unit weight and stiffness per unit weight. Full utilization of the axial fiber properties is seldom achieved.

This is because fibers of different orientations are required to carry loads which are applied in different directions. Figure 1 shows the properties of unidirectional versus woven fabric materials. However, even with woven or laminated materials with various directions of fibers, composite materials have very good specific properties when compared to metal.

Table 1

Chopped Fiber Reinforced Composites

	Flexural Modulus PSI	Ultimate Tensile PSI	Yield PSI
Nylon 6/6	390,000	12,000	8,000
30% glass	1,300,000	28,000	-
Polycarbonate	340,000	9,500	9,000
10% glass	500,000	9,600	-
30% glass	1,100,000	19,000	-
30% graphite	1,900,000	24,000	-
40% graphite	2,800,000	24,000	-
Polysulfone	390,000	9,700	10,200
30% glass	1,050,000	14,500	-
30% graphite	2,000,000	23,000	-


GENERAL COMPARISONS BETWEEN GRAPHITE UNIDIRECTIONAL, GRAPHITE FABRIC AND GLASS FABRIC/EPOXY LAMINATES

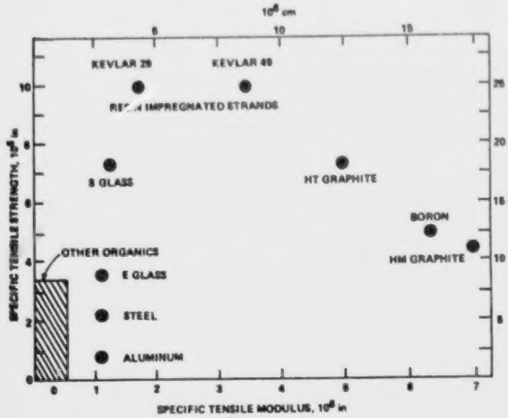


Figure 2

DESIGN

The chopped fiber composites are usually designed with the same methods used for metals. Some anisotropy can occur if there is alignment of the fibers during molding, however, this usually does not have to be considered. The method of analysis for continuous fiber composites can be very involved. However, for most rehabilitation devices "Netting Analysis" can be used. This assumes that the fibers carry all of the load and that there is no shear strength in the material. Shear loads are picked up by placing fibers at 45 degrees to the load. It is also important to have the layers balanced with respect to the centerline of the composite to prevent warping. One of the biggest design problems is joining various components together. The designer always strives to keep the number of pieces to a minimum. The molding methods of manufacturing facilitate this approach. If screw attachments are indicated, usually threaded metal inserts are used. Often bearing surfaces are integral with the part since many composites have excellent friction and wear characteristics.

Table 2

Fiber Properties

	Density lb/in^3	Ultimate PSI	Compressive PSI	Elastic Modulus PSI
High Modulus Graphite	0.0707	300,000	-	58,000,000
High Strength Graphite	0.0524	325,000	215,000	34,000,000
"S"glass	0.09	325,000	215,000	12,600,000
Kevlar	0.0524	325,000	70,000	19,000,000

MANUFACTURING METHODS

There are a multitude of methods for the manufacture of composite materials. Some are better for high production and some for low production and making prototypes. Chopped fiber reinforced composites provide significant increases in strength and stiffness over the neat (unreinforced) polymer. Table I compares the properties of some typical chopped fiber reinforced polymers. For large production runs very inexpensive parts can be made (cents per part). However, significant up front mold costs must be expended. It is possible to make low

Table 4

Price Estimates 1985

Kevlar 49	$13-18 lb
Graphite	$12-18 lb
Glass	$2.5-7.0 lb

volume parts by this method at slightly higher cost per part. There is a laboratory injection molding press available which requires only small amounts of polymer to load up the barrel and semi automated production can be run on the machine. We have such a press (Morgan Press) at the Harrington Center. Temporary molds can be made at relatively low cost by machining a positive of the part and casting a urethane or epoxy high temperature molding compound around it. Epoxy molds should last for over one thousand shots. Some molds have lasted for over 50,000 shots. Dimensional tolerances can not be held as well with the castable molds because of their lower modulus. However, for most pieces used in assistive devices the quality of the part is more than adequate.

Another way of fabricating chopped fiber composites is by compression molding. Sheet or bulk molding compound which contains partially cured resin and chopped fibers is commercially sold. A preweighed amount of the material is placed in the mold. Molding generally takes a few minutes. Again, the molds are expensive, but part costs can be low if the intial capital costs can be amoritized over a reasonable production volume. Polyester is primarily used for the resin. Preforms of fiber mat are also used in compression molding.

Continuous fiber reinforcement of polymers creates materials which are competitive in properties with metals. Table III shows some representative continuous fiber composite material properties. Prepregs of continuous fiber composites can be obtained. Prepregs are prepared by impregnating the fibers with a polymer and partially cureing it. The result is a flexible and tacky tow or sheet which can be layed up in a mold or around a mandrel, put under pressure and fully cured. Another way of fabrication is to lay up the fibers in a mold and impregnate them with a liquid polymer, put them under pressure and cure. There are numerous methods of applying pressure. One easily implemented method is to lay up the material in a mold, cover the mold with elastic sheeting and seal the sides. A vacuum is pulled on the inside of the "bag" and the assembly cured. Bleeder cloths and peel plys are needed inside the bag to provide a path for the air during the evacuation process and to provide a sponge for the excess resin. The molds for this vacuum bag molding technique are less expensive than for injection or compressive molding because there is not two halves that have to match. Vacuum bag molding is very labor intensive and thus it is better suited for moderate production volumes. Variations of this technique are to pressureize the outside of the bag by creation another cavity above the bag and forcing compressed air on top of the bag or to put the vacuum bag into an autoclave. This illustrates the major problem of continuous fiber composite manufacturing high labor content. The aerospace industry is automating much of the layup work but this is not applicable to rehabilitation components. For simple geometric shapes, reasonable cost parts can be made by several methods. For tubes, there are several methods of inexpensive manufacture. A core of foam can be used as a mandrel for tape winding and the outside pressurized by wraping the composite with Mylar tape which shrinks with heating. Also an inflatable tube such as a Penrose drain can be used to expand the inside of the tube against a mold. The inflateable tube can be left in the cured part.

Pultrusion is also a method of making tubes. It is a high production method but if a pultruded part used in other devices can be found, the cost can be very low. Pultrusion consists of pulling fibers which are impregnated with resin or which are prepregged through a heated die. A continuous piece of constant cross section is obtained. Pullforming is a variation of this in which the fiber tow is pulled into a mold after going through the die. Curved parts and variations in cross section can be obtained.

The simplest method of manufacturing is the hand lay-up method. An inexpensive mold can be fabricated because low temperatures and pressures are employed. It is not uncommon to use plaster or wood. A gel coat is first applied to the mold to provide a smooth surface. When the gel coat is tacky the fibers, usually in the form of mat or a woven cloth, are pressed into it. The resin is then applied to the fibers and squeegees or rollers are used to densify the composite. This procedure then is repeated until the desired thickness is obtained. Usually a room temperature curing resin is used.

CONCLUSIONS

Composite materials should be used more widely in rehabilitation devices. Their specific strength and specific stiffness properties provide for better mobility and less energy consumption on part of the user. Low cost methods of manufacture must be utilized to a greater extent. Simplified design methods and manufacturing methods exist for moderatee production parts.

ACKNOWLEGEMENTS:

The Harrington Arthritis Research Center would like to thank the Flinn Foundation for funding research in the assistive devices area.

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DESIGN AND IMPLEMENTATION OF AN EVALUATION PROGRAM FOR ASSISTIVE DEVICES USED BY PEOPLE WITH ARTHRITIS

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ABSTRACT

Current sources on assistive devices lack sufficient information so that prospective users are not able to make informed choices with regard to short and long-term usefulness of products for purchase. The Harrington Arthritis Research Cener has undertaken the design and development of an evaluation program of assistive products used by people with arthritis. Special significance was given to the functional performance of devices including effectiveness, overall usefulness, design features, therapeutic assessment, and user satisfaction.

INTRODUCTION

Although assistive devices are listed by product type and manufacturer, little or no information is given regarding performance or therapeutic value. People needing such products find that technical information, functional assessment and cost comparisons are difficult to obtain.

The Harrington Arthritis Research Center has initiated an evalution program directed at people with arthritis who have need of assistive products. An Advisory Board was established to guide this program. Members of this multidisciplinary board include clinicians, allied health professionals, engineers, and handicapped individuals.

THE EVALUATION PROGRAM

An interdisciplinary evaluation team consisting of industrial designers, a bioengineer, a psychologist and occupational therapists was directed to design and develop an evaluation procedure for various types of technical devices. The structure and system applied to this procedure take into account four basic areas of product assessment, marketing, engineering, design, and therapeutic needs.

THE EVALUATION PROCESS

Assistive products are purchased and evaluated in the following manner:

Marketing

The buyer and user are not necessarily the same person. Institutional settings often require product buying and stocking for future use, buying for economies of scale, etc. Questions related to storage, product set-up, and maintenance must be considered. Previous product experience and other life experiences can affect user's perceptions and values related to product design, features, and cost. The marketing evaluation should include a complete product description, notations of special features, and cost breakdowns related to model types.

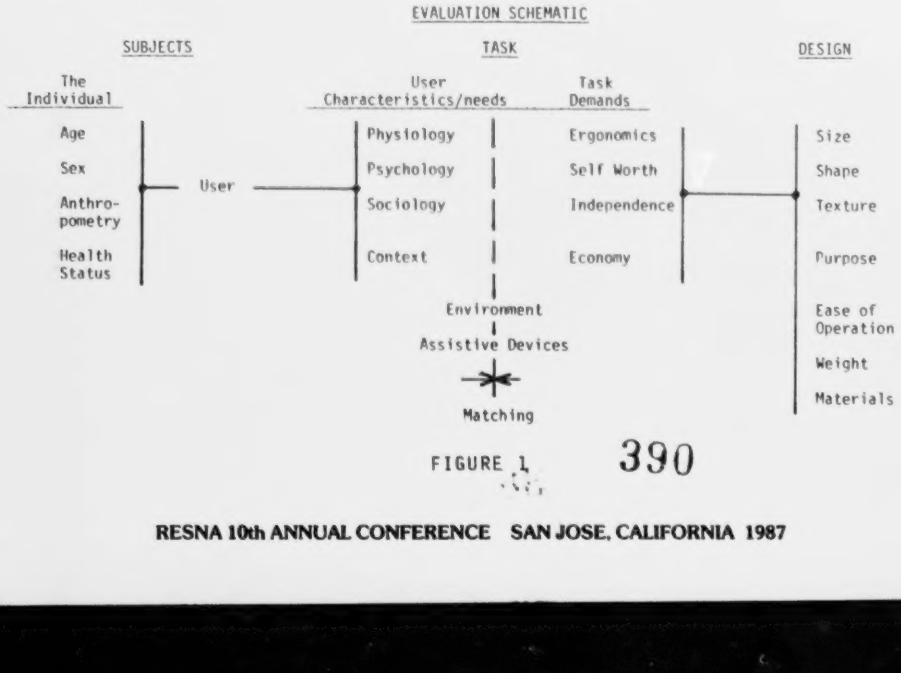
EVALUATION SCHEMATIC
SUBJECTS
TASK
DESIGN
The Individual
Age
Sex
Anthropometry
Health Status
User
User Characteristics/needs
Physiology
Psychology
Sociology
Context
Task Demands
Ergonomics
Self Worth
Independence
Economy
Environment
Assistive Devices
Matching
Size
Shape
Texture
Purpose
Ease of Operation
Weight
Materials

FIGURE 1

Engineering

Relative human energy needs must be assessed and considered with respect to functional needs. Issues concerning product system, structure, materials used, and their effect on quality and safety must be evaluated and related to cost and value. All aspects related to bioengineering and their affect on user performance must be measured.

Design

Task needs and design concept must match (Figure 1) and visual appearance must support the user's sense of aesthetic value and taste.

Therapeutic Needs

Short and long-term needs must be met in overall user therapy.

1. Client criteria in choosing devices: Persons with a functional disability will usually be unaware of its cause. They will be unable to answer questions accurately about which joint or which range, etc., is the problem. Clients will, however, be perfectly able to give the most important of criteria: does the thing work for increased ability in an activity. Their own purpose, method, and satisfaction are vital pieces of information.
2. Occupational Therapist's selection of devices: The primary professional determination of need for a device and its choice with client input are made because of judgements about stress and joint trauma in functional activity. Assistive devices should be used only in accordance with the primary principle of joint protection: All joints should be used at maximum range and strength consistent with the disease process. If performance without a device is possible, three criteria are used to judge whether a device or technique is nevertheless necessary. 1. Is there severe pain during or after the activity? 2. Does the activity require continuation after a point of fatigue? and 3. Are there unstable joint positions or motions?

Other ideas which might be kept in mind as evaluation tools are developed are these:

1. Presence or absence of visable deformity has no bearing whatever on the need for a device.
2. Measurements of joint range and strength are "subjective." Especially in acute disease, but also in other phases of arthritis, these measurements change within the course of a phase of the disease and even in the course of a single day. The most frequent limitation of range or strength is pain during the test.
3. All devices should be considered temporary measures until more normal function is possible. Need for various kinds of devices changes as joints change in ability to function during the disease process and during a single day.
4. A device may "save" one joint only at the expense of another. For example, shoulders often suffer at use of the forearm support walker; hands at the use of ordinary walkers. Priorities of function must be determined.
5. Reachers do not substitute for hand function. They are usually needed in case of back conditions or lack of hip motion or shoulder motion. People with hip replacements need reachers for several months to get dressed. Some of these people have good hand function and others do not.
6. Patient surveys will reveal information about what is occurring between people and devices. No information can be gained about possibilities of function, trauma in activity, better substitutions, etc.

Assistive products must also be considered in relation to other devices such as wheelchairs (Figure 2) or walkers. Products work together in harmony of function and overall system concept.

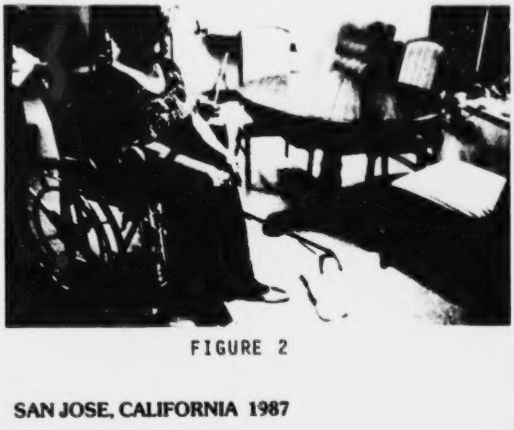

FIGURE 2

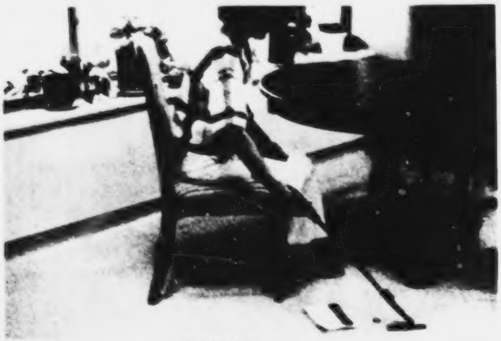

FIGURE 3

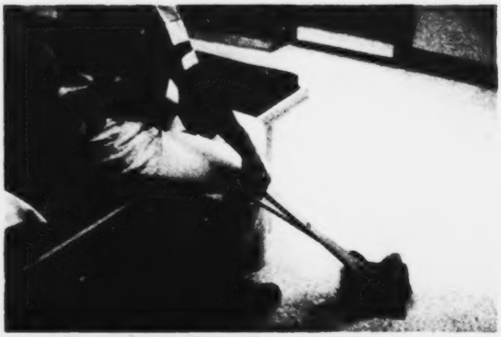

FIGURE 4

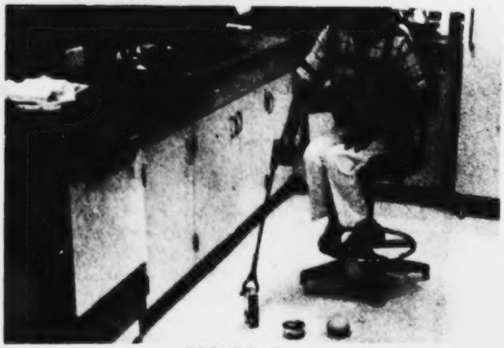

FIGURE 5

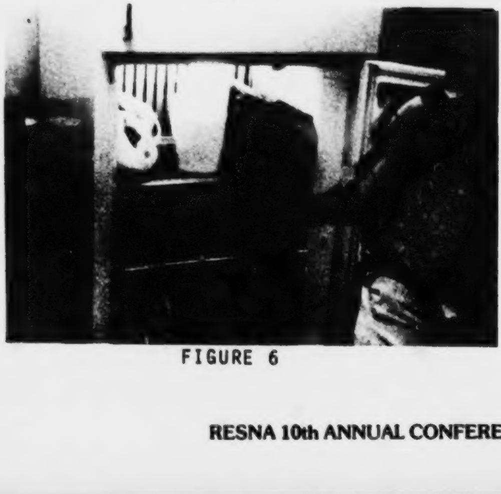

FIGURE 6

SUBJECT CLASSIFICATION

Human subjects were classified (type A, B, or C) as a function of the progression and stage of their disease (arthritis).

Class A

Those individuals who do not present to the examiner any noticeable joint damage (i.e., loss of motion, dislocation, subluxation, nodes) and/or change in the mechanisms surrounding the joints (i.e., swan neck deformity, contractures). This is true for the entire body. (X-rays were not utilized due to the limited time factor and lack of funding sources to pay for x-rays.)

Class B

Those individuals who present any joint change/damage that is related to their diagnosis. Any joint in the body may display the change.

Class C

Those individuals who display severe joint changes which would also be described as "late stages" of a deformity (i.e., dislocation, subluxation, ankylosing) with evidence of muscle atrophy and significant loss of strength.

PILOT STUDY

Task

A specific task scenario was developed under the pilot study which takes into account daily living needs of users. Subjects were observed moving through this set of tasks. Written and photographic records were made and used in determining product function (Figures 3, 4, 5 and 6).

The findings of the study support the design and method of the proposed evaluation process by highlighting various problems associated with different reacher types. Some examples:

- Some reachers cannot meet certain task requirements.
- There is a correlation between the time it takes for a task and the certainty of doing it.
- Many design details are at odds with good function.
- Reachers are designed for use with one arm but might be better if both arms and hands could be used.
- Latching (fixed object gripping) seems to provide better control and user confidence.
- Males tend to "power through" tasks, that is they use strength rather than proper form in using a reacher.
- Standing is often preferred to sitting while using a reacher.

INCREASED INDEPENDENCE THROUGH MORE ACCESSIBLE SECURITY

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ABSTRACT

This paper presents the complete design philosophy for an automatic deadbolt lock with all the constraints imposed by the special needs of the disabled population. The main concentration of the design was on pre-existing parts. The main actuator was made from a power door locking system of an automobile. The high current supply came from a capacitor charge. The design was made to mesh with the existing door opening mechanism, using the existing lock on the door. Finally, when the door opener was operated, the door unlocked automatically.

The locking system is currently being tested. The subject performing the test, before installation, was unable to enter or exit his apartment without assistance. With the device installed, he is able to enter or exit his home at any time, thus increasing his independence.

INTRODUCTION

Daily we lock our houses and apartments to keep ourselves and our property safe. This type of lifestyle is often a problem for a person with limited hand and wrist use. Unable to lock their door, they must rely on outside assistance, which decreases their ability to be independent.

Many electric door locks are available on the market today. Most require extensive modification to the existing door and frame, while many are not economically feasible. A door locking and unlocking system was designed for simple installation using the existing structure, and one that was not cost prohibitive. In addition, a deadbolt lock was desired for its increased security.

BACKGROUND

The Cerebral Palsy Research Foundation of Kansas (CPRFK) in cooperation with The Wichita State University (WSU) College of Engineering has a grant with the National Institute of Handicapped Research (NIHR) to establish a Rehabilitation Engineering Center (REC) to do research in the core area of "Modifying the Worksite to Enhance Employability". In response to the research accomplished, CPRFK started Center Industries Corporation (CIC) both as an opportunity for employment for persons with disabilities and as a laboratory for the research being carried on.

It has been the philosophy of CPRFK that housing is a crucial element in the whole life environment of any individual. To provide more opportunities for independent living to people with disabilities in the Wichita area, an accessible apartment complex, Timbers, was initiated by CPRFK. This HUD supported housing project consists of 100 apartment units spread over a 10-acre site in the city. The 24 one-bedroom apartments comprising the congregate area are reserved for those persons with the most severe disabilities who require some form of daily attendant care. The remaining 76 units are in four-plexes or six-plexes surrounding the congregate area and are one-bedroom and two-bedroom apartments. These are for those with less severe disabilities who contract for attendant care on an as-needed basis. All are built for autonomous living and complete accessibility throughout the apartment unit and between apartments. In order to validate the research concepts related to independent living, the REC utilizes this facility as its laboratory. Many of the tenants living at Timbers participate in the research projects of the REC; many also work at CIC.

The population served by the REC primarily consists of brain damaged individuals, developmentally disabled or through trauma. Persons served are primarily those individuals with cerebral palsy; however, persons with multiple sclerosis, muscular dystrophy, Friedreich's Ataxia, spina bifida, and post trauma brain damage are also served. The population consists of normal to near normal intelligent individuals who desire the independence that a job and their own apartment afford. They patiently serve as research subjects for REC research projects and provide a wealth of information on the expectations of persons with disabilities of vocational rehabilitation engineering and independent living.

PROBLEM DESCRIPTION

Living at the Timbers Apartment Complex had its difficulties. These difficulties were mostly known to the tenants of the centrally located 24 apartments. The problem started as being insignificant, but then grew to become intolerable, threatening the personal belongings and even the safety of the tenants.

The problem, simple at first, was a door lock. These door locks, deadbolts, were operated with a key from the outside and a rotational handle from the inside.

But the tenants, more often than not, were unable to operate these locks. This is where the problem begins, but not ends.

Unable to lock or unlock their door, the tenants had two choices, to call an attendant for assistance, or to always leave the door unlocked. Neither of the choices was a solution, one threatening independence, and the other threatening security, both of which everyone desires. As time passed, the problem went solved as such, with the tenants making the choice between freedom and security.

Just when it seemed as though a happy medium had been reached the problem grew. Thieves and vandals began to prey on the area. The tenants of the Timbers were easy prey, and unable to defend themselves. Furthermore, the tenants used prescription drugs, something of great value to abusers. An unlocked front door allowed thieves to enter the apartments and take what they wanted. Furthermore, many tenants began to fear for their safety. The temporary solution to this was obvious. The tenants must sacrifice independence for security.

So, the initial problem of unlockable doors grew. For the tenants it became a choice between freedom and security. For the authors, there was no choice, a solution had to be found that guaranteed both independent living and peace of mind for personal safety.

APPROACH

The problem was approached with integration in mind. It was desired that the design function well with the existing door openers, doors, and door locks. To begin the approach, a description of the existing hardware needs to be given.

The tenants for the central 24 apartments had a pre-existing mechanism to open and close the front door to the apartment. The mechanism is a Sear's electric garage door opener. The motor and gearing of the opener is located in the attic directly above the apartment. Through a small hole in the ceiling, a cable is attached to the door handle. To open the door a button on the wall is pushed. An added feature to this system is remote control. The door openers can be operated by the remote control units that come with every garage door opener. This added convenience allows tenants to open their doors from the outside or the inside with the push of a button.

The second part of the pre-existing hardware is the door lock itself. This lock is a deadbolt, one of the most secure types of locks. For security and cost reasons, use of the existing deadbolt locks was desired.

The last step of the approach is to define the capabilities of the tenants. It has already been stated that most of the tenants were unable to operate the key part of the lock, or the rotational handle on the lock. By observation, it was found that all of the tenants, in some way or another, could push a button.

One final restriction applied. The lock must be accessible with a key in case of emergency. This meant that whatever method was found, it must not restrict entry into the apartment, especially in event of power failure.

At this point, the authors concluded that the solution to the problem would be a device that would turn the lock handle for the tenants. Furthermore, this device must be powered by the power available from the existing door opener. Lastly, the solution design must be actuated with the push of a button. The design had begun.

SOLUTION ACHIEVED

To complete the solution, devices able to turn the lock for the tenants were investigated. Included in the initial investigation were motors and solenoids.

After working with these two devices, we found that the most obvious solution is not always the best. The motor worked great, but because of the gears required, outside access with a key was impossible. The solenoid also had a problem. It was not possible to find solenoids with sufficient stroke or power. In other words, the solenoid was unable to fully lock or unlock the door. Then an observation occurred.

Power door locks on a car operated exactly as the design problem required. They were powered electrically, they could be key overridden, and they operated from the push of a button. These door locks operate with a device called a rotational solenoid. It is much like a motor, and yet has characteristics of a solenoid. A standard solenoid pushes a rod in and out. This device rotates a disk that drives a rod in and out. The device fit all criterion, except one, it must mesh with the existing door opener.

To use the solenoid in a home, required a direct current (DC) power source, which is standard on automobiles. The existing door openers had a DC power supply available. This power supply did not provide sufficient current to operate the rotational solenoid. To overcome the problem, the small current was allowed to build up in a capacitor, and the push of a button caused this built up energy to be released all at once. This energy build up provided enough energy to operate the deadbolt lock.

With the major parts of the problem solved, the authors went on to complete the device. The final design was integrated with the existing remote control system to provide a system that will open and unlock the door be remote control. Remote control of the locks allowed the tenants to use the handheld remote units as the "key" to the door. These new keys provided the tenants with freedom to come and go at will, and provided the security that was much needed.

RESULTS

The design of the door locks are a "low tech" design. Low tech means all parts are easily available and have been for many years. This type of design was pursued because of the reliability and repairability of the device.

Another benefit of these off the shelf parts is cost. Most tenants live on a fixed income and are unable to pay high installation and repair bills. All parts used can be purchased by any individual in single units or in bulk discount quantity.

Finally the design is easily repairable. Extra units were produced for ease of repair. The apartment maintenance personnel simply replace the defective device with a new one and take the defective device to their workbench for repairs.

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PERFORMANCE ASSESSMENT OF ENVIRONMENTAL CONTROL UNITS AS USED BY HIGH LEVEL SPINAL CORD INJURED PERSONS

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ABSTRACT

This paper presents an evaluation and analysis of the effectiveness of environmental control units (ECUs) in meeting the needs of high level quadriplegics. Pertinent data was obtained by conducting a survey of twenty-nine quadriplegics. Functional performance and product effectiveness in terms of benefits to the user are assessed by determining the frequency of various actions or activities, importance of diverse functions, and importance of possessing or having access to the unit itself.

INTRODUCTION

Environmental control units have long been prescribed for quadriplegics as a means of providing them with an opportunity to exist in a state of independent living. The functions and capabilities of ECUs are adequately described elsewhere, along with advances being made in the technical state of the art by assorted manufacturers (1). While the costs of acquiring an ECU are readily determined, the effects of ownership and use of ECUs have not been sufficiently examined. The physical and psychological condition of the target market for ECUs, i.e., quadriplegics, is ordinarily such that any device which may aid or enable them to increase their functionality or maintain any degree of independence whatsoever is seen as beneficial. When recommending or prescribing ECUs, the occupational therapists, physicians, and others must generally rely on equipment that is currently available whether or not it is exactly suited to the particular needs of a given quadriplegic. Often in business a market is identified, and then a product is designed and sold to the customer without first thoroughly assessing what the customer considers most important in the product. There is little doubt that ECUs do satisfy many of the needs of the users, and that many ECUs can operate large numbers of appliances. Therefore the goal of this study is to illuminate those functions and benefits considered most important to current users of ECUs.

METHODS

The subjects responding to the survey were 26 male and 3 female spinal cord injured quadriplegics with ages ranging from 8 to 68, and a mean age of 32. The level of lesion ranged from a C-1 brain stem to C-6. Each of the subjects were injured at least a year prior to participating in the study. This constraint was intended to reduce possible skewing of the data due to the typical adjustment period following such a traumatic injury. All the subjects at the time of the survey were in good health, and all the subjects retained full mental acuity as well as normal vocal abilities.

The subject selection process consisted of soliciting various local St.Louis agencies or national manufacturers of ECUs to either provide a list of acceptable contacts or to actually distribute the survey to a small group of their customers or clients. The organizations agreed to provide a balanced distribution of users with respect to the users' level of satisfaction with the ECU. Interviews in person or by telephone were conducted with several of the local area subjects.

The survey contained questions encompassing demographics, ease of use, frequency of use, and perceived benefits. The questions were phrased in such a manner as to elicit qualitative responses in the form of dichotomous selections, rank order, rating scales and multiple choice. Due to the small sample size and limited control over the randomness of subject selections, the survey results are intended to be descriptive and informative rather than reliable predictors of the population at large. Because of the qualitative nature of the responses, the data were analyzed and results conveyed using simple descriptive statistics.

RESULTS

Subjects were asked to rank in order what they considered to be the most important functions controlled by their ECU. The function selected most often as first choice was the telephone, with 60.7 percent of the sample (table 1). Television was the first choice for only 21.4 percent of the subjects. 30.4 percent of the sample selected the control of room lights as the second most important function, followed by 21.7 percent for television and 17.4 percent for emergency signal/nurse-call capability. The number of subjects specifying functions of secondary importance was slightly less than the number specifying primary importance because some subjects felt that the remaining functions were of equal importance.

Function	1st Choice	2nd Choice
Television	21.4%	21.7%
Room lights	3.7	30.4
Em. Signal	3.7	17.4
Telephone	60.7	13.0
Computer	0	4.3
Radio	3.7	0
Door	3.7	8.7
Other	3.7	4.3
	n=28	n=23

Table 1. Ranking of Various Functions in Order of Importance

Specific benefits as perceived by the users were investigated. 40.7 percent of the sample stated that enhanced ability to communicate was selected as the primary benefit of the ECU (table 2). 22.2

percent selected security and health as a first choice, and only 18.5 percent selected recreation and entertainment as the primary benefit. When asked directly, 59 percent strongly agreed and 34 percent agreed that the ECU provided them with independence. The remaining 7 percent felt neutral toward the issue, and no one disagreed.

Benefit	1st Choice	2nd Choice
Education	0%	4.3%
Security/health	22.2	30.4
Employment	3.7	0
Communication	40.7	13.0
Household-activities	11.1	4.3
Recreation	18.5	43.5
Other	3.7	4.3
	n=27	n=23

Table 2. Ranking of Perceived Benefits in Order of Importance

Noting the importance of various functions and benefits is essential in assessing the effectiveness of the ECU as a device for independent living. Additionally it is necessary to determine what activities the users engage in most often, and whether the unit is used in performing or initiating an activity (table 3). Interestingly, 57 percent of the sample indicated that they use the ECU in conducting the activity with which they spend the most time.

Activity	% Chosen as #1	% Chosen as #2
Television	42.9%	8/9%
Listen to Music	4.8	0/1
Computer	4.8	1/1
School	23.8	2/5
Work	19.0	0/4
Read	4.8	1/1
	n=21	

Table 3. Ranking of Activities in Order of Time Involved

In many instances, agencies such as the V.A. or insurance companies will provide the needed capital only if the device is determined to be medically necessary. The results of this survey support the concept that the ECU is valued for performing functions essential to independent living. For example, even though watching television ranked as the highest first choice activity, it trailed a distant second behind the telephone in importance of functions. Recreation and entertainment were also surpassed by communication and security/health as the benefits perceived as most important.

School and work, whether volunteer or paid, do not appear to use the ECU to any great extent (table 3). Possible reasons for this may be that the work is not performed at home, or that other electronic assistive devices are more efficient at interacting with required job tools, such as personal computers.

CONCLUSIONS

It is evident that the ECU is an integral part of the daily routine of many users and it appears to satisfy the intended goal of aiding the disabled to maintain a more independent life style. According to the results of this survey, the typical ECU should be designed in such a way that telephones, intercoms, and emergency signal capabilities are all standard components of the unit. The use of the ECU as a vocational rehabilitation device is, according to these results, a questionable goal.

ACKNOWLEDGMENTS

The author wishes to thank the Prentke Romich Co., Du-It Control Systems Group, and Computerized Enabling Systems for their assistance in distributing the survey. I would also like to thank Becky Vail of the St.Louis Veteran's Administration hospital for her contributions.

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COST EFFICIENT TECHNOLOGY FOR REHABILITATION-THREE EXAMPLES

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ABSTRACT

The Office of Technology Assessment (OTA, 1982) called for "appropriate technology" applied to needs in the rehabilitation setting.

This paper presents three cost efficient examples of tools developed for specific rehabilitation situations: 1) a heel-knee caliper for height calculation, 2) an articulated utensil handle, for evaluating personal feeding capabilities, and 3) an extended chalk holder for use from a wheelchair. These tools matched the real needs of the practitioner and clients. Results suggest that simplicity of design, and low-cost may contribute to the acceptance of technology by the end-user.

HEEL-KNEE CALIPER CALCULATIONS COMPARED WITH RECALLED MEASURED HEIGHT

Background

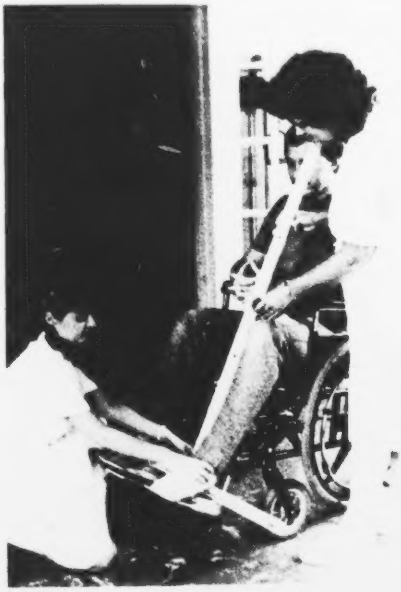
Valid estimates of body dimensions are needed for nutritional assessment purposes. A subject's height is necessary to determine ideal body weight. Loss of height is an indicator of the development of osteoporosis. If an individual is unable to stand, or be placed in an extended posture to allow a full-body measurement (nonambulatory persons, or those with kyphosis) an alternative height estimate is necessary.

Osteoporosis results in decrease in bone mass. As bone mass in the vertebrae decreases, vertebrae become wedged and may collapse with severe back pain. When several thoracic vertebrae collapse, height loss and kyphosis develops. These symptoms make ordinary height measurement difficult, but measurement remains essential.

Methods

Heel-Knee calipers were constructed using a steel meter stick with a horizontal base attached at a 90 degree angle. A sliding top piece was mounted to the vertical arm with a screw down knob. With the subject sitting with feet on the floor at a 90 degree angle, the fixed horizontal arm of the caliper was placed under the left heel. With the meter stick shaft of the caliper held parallel to the shaft of the tibia, the upper arm of the caliper was lowered to rest on the patella and the knob tightened. Measurement was recorded to the nearest 1/16 inch.

Subjects recalled their tallest heights. Standing heights were then measured for each subject. The recalled heights for eight of the clients (20%) could not be remembered by the client. Recalled heights of the others were reliable.



Results

Measured heights of (N=40) subjects ranged from 59 inches to 72 inches, with a mean of 64 inches and median of 63.6 inches. The data obtained with the heel-knee calculations, using Chumlea et. al. formula (1984) were accurate in estimating the heights for both males and females. Percent difference (between measured and calculated heights) for males had a range from 0.07% to 4.26% with a mean of 1.87%. For females the range was 0.27% to 7.17% with a mean of 2.38%. Correlations among the height estimate techniques were observed with significance at the five percent level.

Table showing significant correlations among height estimates:

Variables	Correlation	Significance
Calculated Height With		
Recalled	0.424	0.0154
Measured	0.626	0.0001
Heel-Knee	0.546	0.0392

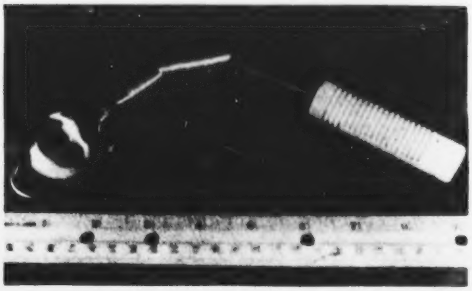
Discussion

Results indicate that where full-height measurements are not feasible an inexpensive and reliable alternative method is of the heel-knee caliper.

AN ARTICULATED UTENSIL HANDLE FOR ASSESSMENT ASSESSMENT OF SELF FEEDING SKILLS

Background

A 12 year old girl, with athetoid cerebral palsy was unable to feed herself. Assessment of her functional motor capabilities revealed the need for a utensil with built-up handles and bent at an angle for possible self-feeding. Standard utensils were not functional because her athetoid movements and intention tremor became increasingly more pronounced as she brought her hand closer to her mouth. A customized eating utensil was designed with: 1) extended handles built up to her grip and 2) bent angle to compensate for her wrist supination.



Methods

Aluminum rod stock was cut into three sections, and attached together with pin hinges. A bicycle handgrip was cemented to one section; and the other slotted to accept a spoon or fork. A series of feeding trials were made. When the best angle settings were found, the model was used to construct a permanent, rigid spoon which could be used and washed in a conventional manner.

Results

This tool proved to be useful for evaluating the special needs of this client, who was able to eat in the facility cafeteria with her peers. Later, she used this spoon in a less restrictive "mainstream" school setting.

AN EXTENDED CHALKHOLDER

Background

A functional skill required of school teachers is the use of blackboards. Overhead projectors are not always available. A teacher in a wheelchair may have difficulty using the chalkboard.
A college student with a C6 SCI was enrolled in education practicum course. He experienced difficulty in using the chalk board. He fatigued in grasping the chalk, and he could only use the lower portion of the blackboard. A search of ABLEDATA in NARIC database revealed no commercial solutions.

Methods

A 30' retractable claw for retrieving small parts and objects was purchased from a hardware store. A lightweight, titanium tube with the same diameter was cut to a length equal to the retrieving tool. With the retractable claw extended through the tube, the plunger was extended to clasp the 2" piece of chalk to the distal end of the tube with adequate tension.

Results

The student teacher reported that this tool was useful. It is portable, durable, and can be easily reloaded by the client with a fresh piece of chalk.

Discussion

This design was a simple solution, utilizing inexpensive materials, and required no special shop skills or tools.

ACKNOWLEDGEMENT

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Special Interest Group 8

Sensory Aids

Chair: Judith Harkins, Ph.D.

SENSORY AIDS SIG

Co-Chairmen
Judith E. Harkins and Lawrence A. Scadden
Gallaudet University   Electronic Industries Foundation

The program of this 10th Annual Conference attests to the growth of research on applications of technology to the needs of people with sensory impairments. The Sensory Aids SIG is pleased to present two scientific symposia--one that gives an in-depth look at one type of sensory aid and a second that provides a sampling of new devices and techniques being developed for blind, deaf, and deaf-blind persons.

The first symposium, New Generation Hearing Aids, covers the most recent work toward restoring hearing through the use of digital signal processing techniques. Dr. Harry Levitt, Symposium Chairman, has designed a program that covers a wide array of technical topics and evaluation issues in new generation hearing aids and amplification systems. The symposium is divided into two parts and begins with an overview of digital hearing aid technology. A series of invited papers follows from scientists and engineers from Central Institute for the Deaf, Massachusetts Institute of Technology, Nicolet Audiodiagnostics, and the VA Medical Center of Martinez, California. In the second part of the symposium, contributed papers from the Lexington Center and City University of New York describe the results of an ongoing project devoted to digital hearing aid technology.

The SIG's second symposium, Innovations in Sensory Aids Technology, covers recent developments in devices and systems designed to assist with a variety of activities of daily living. Functions covered by these devices and systems include reading text, conversing by telephone, face-to-face communication, and following a daily schedule.

In addition to the two scientific symposia, the SIG's poster sessions provide an interesting sampling of devices, user surveys, and engineering techniques. Most of the poster presentations describe work in the area of visual impairment.

An interesting and commendable feature of this year's submissions to the Sensory Aids SIG is the increase in user surveys and human-factors studies designed to improve the match between technology and users' preferences.

In summary, the 10th Annual RESNA Conference offers more in the sensory aids arena than has been true in past years, and we hope to see this growth continue.

Digital Hearing Aids

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ABSTRACT

Advanced signal-processing techniques, often employing digital methods, are being used increasingly in modern hearing aids. This paper provides a brief summary of the different types of signal-processing hearing aids. These include all-analog programmable or adaptive hearing aids, digitally-controlled analog units, quasi-digital hearing aids, all digital systems using time-domain processing, and all-digital systems using frequency-domain processing. The relative advantages and disadvantages of these different types of hearing aids are discussed.

INTRODUCTION

Recent advances in signal-processing technology have paved the way for the development of programmable, adaptive hearing aids. The key element of a programmable hearing aid is that the electroacoustic characteristics of the hearing aid can be adjusted by an external instrument (e.g., a computer). An adaptive hearing aid is one in which the electroacoustic characteristics of the hearing aid are adjusted automatically so as to improve performance, e.g., by improving intelligibility, speech quality, signal-to-noise ratio, or some other desirable property of the amplified acoustic signal. The process of adaptation could take place during the prescriptive fitting of the hearing aid and/or while the hearing aid is in use; e.g., adapting to changes in the speech signal or background noise that typically occur in everyday communication.

Digital signal processing techniques are being used to an increasingly large extent in the development of experimental signal-processing hearing aids. As a consequence, these instruments are frequently referred to as "digital" hearing aids. Some experimental digital hearing aids are extremely complex requiring the use of a large high-speed computer while others are fairly simple and are small enough to be wearable. At the same time, there have recently appeared on the market several hearing aids that incorporate some degree of programmability and adaptive signal processing using conventional analog circuits. It is the purpose of this paper to identify the different types of signal-processing hearing aids that have been developed and to discuss their relative advantages and disadvantages.

TYPES OF HEARING AIDS

Analog Hearing Aids. At one extreme is the all-analog programmable and/or adaptive hearing aid. The degree of programmability of these hearing aids is comparable to that which can be achieved by manual adjustment on a good conventional hearing aid. An important advantage of these new aids is that electronic adjustment of the hearing aid by an external source (e.g., a computer) should allow for more effective prescriptive fitting of the instrument.

A recent development is the growing use of adaptive two-channel compression hearing aids. The multi-channel amplitude compression hearing aid was first developed by Villchur (1). Experimental evaluations of multiband compression systems yielded mixed results (2, 3). The above studies, however, concentrated on the intelligibility of the processed speech signal. It is possible, however, to obtain significant improvements in the quality of the processed signals by appropriate choice of compression parameters and several two-channel hearing aids which achieve this objective are now on the market. These instruments typically improve the quality of the amplified speech signal although they provide little or no change in intelligibility.

The primary advantage of using analog circuitry in a signal-processing hearing aid is that the technology of small, low-power linear amplifiers and filters is well advanced and can be readily applied to this new application. The all-analog signal-processing hearing aids now on the market have utilized this technology very effectively.

Digitally-Controlled Analog Hearing Aids. A class of hearing aids that involves some digital technology but which depends primarily on analog processing of the audio signal is the digitally-controlled analog hearing aid. In such a system, linear analog amplifiers and filters are controlled by digital logic circuitry. As before, a major advantage of this approach is that linear signal-processing technology is well advanced and chips of small size and low power consumption can be developed without too much additional effort.

Graupe et al (4) have used this approach to develop an adaptive filter for improving speech-to-noise ratio in hearing aids. Digital logic is used to determine whether or not speech is present. The characteristics of the analog filter are then adjusted depending on the spectrum of the speech and noise. The use of analog circuitry for the filtering operation and digital circuitry for controlling the filter, facilitated the development of a chip that is small enough and of sufficiently low power consumption to be incorporated in a modern hearing aid.

Quasi-Digital Hearing Aids. A third class of hearing aid is the quasi-digital hearing aid in which the audio signal is sampled at discrete intervals in time, as in a digital system, but the sampled values remain in analog form. A good example of this approach is the switched-capacitance delay-line filter. The incoming audio signal is sampled at regular intervals in time, the samples being stored as capacitive charges in a cascaded sequence. The capacitive charges are switched synchronously so that they move systematically down this cascaded sequence at the rate of one stage per sampling interval. The charge at each stage is multiplied by a weighting coefficient and then summed. This weighted sum is the filter output. The values of the coefficients used in the summing operation determine the frequency reponse of this finite-impulse-response digital filter.

The use of the switched capacitance technique, or other quasi-digital method has the important advantage that digital signal-processing techniques can be used but without the need for analog-to-digital or digital-to-analog converters. The power consumed by an analog-to-digital converter increases with degree of quantization. If linear quantization is used, the resolution of the analog-to-digital converter should exceed 12 bits, (i.e., 1 part in 2**12). The development of high resolution analog-to-digital converters of small size and low power consumption, suitable for use in a practical hearing aid, is a difficult technical problem.

All-Digital Hearing Aids: Time-Domain Processing. The fourth class of hearing aid is the all-digital unit. In this case the audio waveform is not only sampled at discrete intervals in time but each sample is then converted to binary form using an analog-to-digital converter. Many different forms of signal processing can be used in all-digital systems and it is important to distinguish between those forms of signal processing that are analogous to that used in conventional hearing aids and those forms of processing that are fundamentally different. For example, a finite-impulse-response digital filter is not very different in its mode of operation from a linear analog filter. In contrast, a processing system that first divides the signal waveform into a sequence of time windows, derives the spectrum of the waveform within each time window, modifies the spectrum according to a programmed set of rules, and then transforms the modified spectrum to a time waveform is fundamentally different in its mode of operation from that of a conventional linear filter. The first form of processing is referred to as time-domain processing since all operations on the signal involve only the time waveform. The second form of processing involves manipulation of the signal after it has been transformed using either a Fourier or other spectral transformation. The latter form of processing is referred to as frequency-domain processing.

Time-domain processing is much easier to implement and almost all of the experimental digital hearing aids that have been developed thus far use this approach (5, 6, 7, 8). Even with this simpler approach, there are still many difficult technical problems that need to be resolved before all-digital hearing aids are sufficiently practical for everyday use. The major problems are those of power consumption and physical size.

At present, all of the wearable digital hearing aids that have been developed are pocket-sized experimental units. The next generation of signal-processing chips using CMOS technology is likely to satisfy the necessary requirements of power consumption and size. If a practical resolution of the analog-to-digital conversion problem can be obtained, then the all-digital hearing aid that is small enough to fit behind the ear will soon become a practical reality.

All-Digital Hearing Aids: Frequency-Domain Processing. Frequency-domain processing offers many of the advantages of time-domain processing plus some unique additional advantages. Not only is it easier to conceptualize various signal-processing operations in the frequency-domain, but certain operations can only be implemented in this domain. For example, noise reduction by means of spectrum subtraction requires that a running estimate of the average short-term noise spectrum be subtracted from the short-term speech-plus-noise spectrum. Similarly, generalized amplitude compression using an orthogonal polynomial expansion of the short-term power spectrum (9) inherently depends on frequency-domain processing. Looking toward the future, speech-processing hearing aids in which specific phonetic features are automatically extracted and then enhanced, are very likely to depend on frequency-domain processing.

An experimental frequency-domain digital hearing aid has been developed using a MAP-300 array processor controlled by a DEC LSI 11/23 minicomputer (10). A high-speed array processor was necessary in order to process the signals in real time. Although it is unlikely that this system, or its equivalent, could be made wearable in the very near future, the rapid rate of development of digital signal-processing chips is such that a simplified wearable version may be possible in the not too distant future. The present system can be made to simulate a wearable hearing aid by using FM transmitter-receiver links between the hearing-aid transducers worn by the user (i.e., the microphone and hearing-aid receiver) and the array processor.

Even as a non-wearable experimental unit, the frequency-domain digital hearing aid has proven to be a valuable research tool. It has been used to simulate, rather than build, new experimental hearing aids. As a programmable master hearing aid it has provided much useful data on the relative efficiency of various adaptive strategies in hearing-aid prescription. It has also been used in evaluating new methods for reducing the effects of background noise and reverberation.

CONCLUSIONS

Of the various types of hearing aids that have been described, digitally-controlled analog or quasi-digital hearing aids are likely to be the most practical in the immediate future. All-digital hearing aids, which offer greater advantages in terms of signal processing capabilities, are likely to become a practical reality once the problems of power consumption and size have been resolved. These devices will initially employ time-domain processing. In addition to providing programmability and great flexibility in selection of electroacoustic characteristics, these hearing aids will offer important additional features such as adaptive multiband control of signal levels and automatic noise reduction. In the longer term, more advanced signal processing techniques that operate on the frequency spectrum, or on other frequency-like transformations of the time waveform, will be developed in order to enhance specific features of the speech signal so as to improve intelligibility and overall speech quality.

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A Wearable Digital Hearing Aid

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ABSTRACT

Research related to the development of an ear-level, digital hearing aid is described. The work includes the development of a body-wearable digital hearing aid and a computer-aided hearing evaluation system that exploits the flexibility afforded by digital signal processing. A multi-channel hearing aid model that is currently implemented on the experimental hearing aid and an appropriate fitting system for the model are described.

INTRODUCTION

The research that is described herein has been directed towards the development of a practical digital hearing aid that is small enough to be worn at ear level and that consumes small amounts of power commiserate with conventional hearing aids. The work has focussed on: 1) the development of suitable processing structures and 2) the development of modest, but robust processing algorithms that can be implemented on such structures. Preliminary research includes the development of an experimental, wearable version of the digital hearing aid using standard parts that is intended for the study of different hearing-aid models and processing algorithms. In addition, a companion testing system has been developed for a Macintosh personal computer as an experimental system for testing patients and for programming the hearing aid.

Hearing aids that utilize digital methods can provide the flexibility and control of acoustic processing that is required to precisely accommodate the patient's hearing deficiency. When combined with a companion computer-based test facility that measures the patient's hearing and that programs the hearing aid, an optimum fit for the patient can result.

A key feature of this concept is that the final hearing instrument becomes an integral part of the hearing test. Therefore, the audiological test results take into account the acoustic transfer characteristics of the sound delivery tubing and earmold configuration and other variables that are specific to each patient. An obvious advantage of this approach is that fitting errors associated with conventional methods are minimized. In addition, the hearing evaluation and fitting procedure is simplified and shortened with con-committant benefits to the patient including the extra time available for counselling.

As is well known, fitting errors are introduced when a hearing aid is calibrated in a test fixture and an inference is made about what the corresponding sound pressure will be in the patient's ear canal. Similar errors are introduced when the audiometer is calibrated and inferences are made about what the sound pressure will be in the patient's ear canal when the patient is wearing earphones or is positioned in the sound field.

Recent developments with the use of probe systems [1] to directly measure the sound pressure in the ear canal and in situ testing [2] are effective steps that have been taken to eliminate these sources of fitting error. If one then adds the flexibility of a digital hearing aid that can be programmed remotely while the patient is wearing the aid and undergoing testing, an error-free method that is limited only by the performance of the hearing instrument itself can be realized.

BODY-WEARABLE DIGITAL HEARING AID

The wearable digital hearing aid has been developed for clinical field studies and has been described in [3]. It fits into a case 5.5 inches long, 3.5 inches wide, and 1.2 inches thick. The wearable unit is comprised of conventional parts that include a digital signal processor (DSP) chip, digital logic and analog signal conditioning circuitry, multiplexing circuitry, and an analog-to-digital and digital-to-analog converter chip. The analog circuitry is connected via a flexible cable to an ear module containing an input microphone, probe microphone, and receiver. The battery for the system fits within the confines of the body-worn case and provides sufficient power for a continuous period of about eight hours.

The wearable unit can be programmed to implement a variety of hearing aid models. Programs are developed on a separate host computer and transferred to a random access program memory within the hearing aid. A standby power cell is provided within the unit to maintain the integrity of the program in the event that the primary battery becomes discharged or is removed.

Once the unit is programmed, its characteristics can be adjusted via a serial data port. Signal processing parameters are transferred between the fitting system and the hearing aid while the patient is undergoing testing and, in some cases, signal values within the hearing aid are transferred back to the fitting system.

HEARING AID MODEL

A multi-channel, instantaneous compression hearing aid model that has been implemented on the wearable unit as illustrated in Figure 1. Each of the four channels contains a bandpass filter, limiter, and second bandpass filter. The filter-limiter-filter design allows for the maximum output and gain of each channel to be independently adjusted to accommodate the patient's discomfort threshold and hearing threshold. The filters reduce distortion products of the limiting process to ensure that they fall below the masked threshold of the ear.

The advantages of instantaneous compression is that loud, impulsive sounds are prevented from exceeding the wearer's discomfort threshold. The advantage of multiple channels is that high spectral energy in one channel will not unduly distort spectral energy in other channels. Therefore, the design results in a controlled, instantaneous limiting of maximum power output on a frequency-selective basis and minimizes the production of harmonic and intermodulation distortion products that occurs in conventional hearing aids at excessive signal levels.

PC-BASED TESTING SYSTEM

The computer-based fitting system that was developed for the wearable digital hearing aid is quite simple and includes: 1) a Macintosh personal computer, 2) a GSI-16 audiometer with RS232 interface, and 3) an adapter cable that interfaces the SCSI (small computer standard interface) port of the Macintosh to the serial port of the hearing aid. It is possible, with this system, to implement a variety of testing paradigms during which stimulus sounds are presented to the patient, the patient's responses are recorded and analyzed, and the parameters of the hearing aid are varied. The audiometric data can be stored in patient files on the disk and later accessed and reviewed in graphical form using standard spreadsheet and data-base programs.

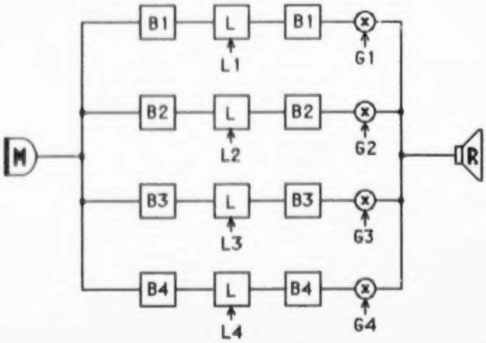
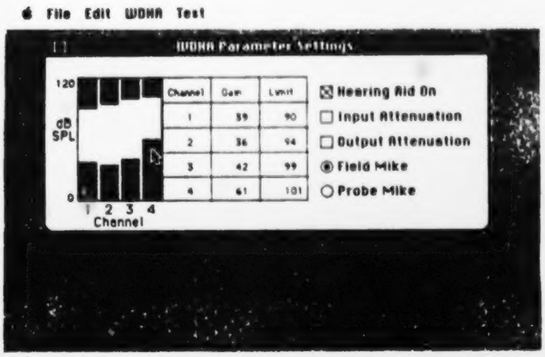


Figure 1. Functional Block Diagram of the Four-Channel, Instantaneous Compression Hearing-Aid Model. The limit and gain parameters can be independently adjusted to control maximum power output and gain on a frequency-selective basis.

The fitting system is currently programmed to support the four-channel model and to measure hearing threshold, discomfort threshold and the upper and lower limits of most comfortable listening. In addition, the system supports certain test features incorporated into the program of the hearing aid.

One program option, that illustrates the general features that can be incorporated into such a system, is shown in Figure 2. With the option display that is shown, the parameters of the four-channel model can be adjusted through an interactive graphics display. The "arrow point" icon is moved around the graphics screen with a "mouse". When the "mouse button" is depressed within one of the bars representing the four limit and four gain parameters, the value of the selected parameter can be changed. The new values are then transferred to the hearing aid. The parameter values, expressed in dB SPL, are displayed to the right of the bar display. The gain is expressed in output sound pressure level corresponding to an input level of normal conversational speech. The program takes into account the calibration data associated with the transducers in the ear module. It should be noted that the menus labelled "File", "Edit", "WDHA", and "Test" at the top of the screen in Figure 2 can be pulled down to reveal other program options that can then be selected.



Channel	Gain	Limit
1	39	90
2	36	94
3	42	99
4	61	101

☒ Hearing Aid On
☐ Input Attenuation
☐ Output Attenuation
● Field Mike
○ Probe Mike

Figure 2. Interactive Graphics Display Used For Setting Parameters of the Four-Channel Model.

DISCUSSION

What is described above is one facet of a research program to develop a practical, ear-level, digital hearing aid and is an attempt to illustrate some of the principles that can be applied. The body-wearable unit and PC-based fitting system is an interim stage intended for field studies involving natural conditions of signal and ambient noise.

An all-digital approach has the potential for significantly improving the performance of hearing aids and the effectiveness of clinical procedures. However, a great deal of work remains before this potential will be realized. The development of a practical, ear-level aid offers challenges in several scientific areas. The first is that of developing VLSI processing structures that are small enough to fit into an ear-level package and that can be powered with a hearing aid battery.

The second challenge is that of exploiting the advantages afforded by digital signal processing. The four-channel model and companion fitting system as described above achieves greater precision of fit and improved signal processing. However, much greater gains in utility are likely to be achieved by incorporating more sophisticated processing.

The third challenge is a need to develop better models of hearing impairment and models of fitting that have predictive utility with regard to speech perception and patient satisfaction. Such models can provide a theoretical basis for choosing one fitting method over another or for selecting appropriate processing algorithms.

Strong research efforts will be required to meet each of these challenges and to develop the potential improvements that can be achieved by applying digital signal processing methods to hearing aids.

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MULTIMICROPHONE MONAURAL HEARING AIDS

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ABSTRACT

In this paper, we summarize our current research on the use of multimicrophone arrays in monaural hearing aids. Consideration is given not only to the problem of interference reduction, but also to the question of coding directional information for monaural listening.

OVERVIEW

Listeners with hearing impairments often have great difficulty in interpreting complex acoustical environments. When the environment contains a number of sources and/or reverberation, their ability to "separate out" the sources, to localize these sources, and to attend to and understand a specific target source, is seriously degraded.

One approach to this problem is to sample the acoustic environment at more than one point in space, i.e., employ spatial diversity. This approach is exemplified by work on directional microphones [6], binaural aids [8], and CROS aids [5], as well as by the research described in this paper.

The general importance of spatial diversity is demonstrated by the fact that almost all natural sensory systems, as well as the more sophisticated artificial ones (e.g., in radar and sonar), employ spatial diversity. The basic logic underlying spatial diversity can be understood by noting that many different environmental configurations can lead to the same signal at a single point in space and that the associated ambiguities in determining the environment from the received information can be drastically reduced by sampling at other points in space. Some of the advantages afforded by spatial diversity in normal human audition are described in the literature on binaural hearing [3].

Our initial efforts to exploit spatial diversity for improved hearing aids have been restricted to multimicrophone systems that form a single output for monaural stimulation. Achievements in this area are important not only for people who effectively hear through only one ear (because of asymmetric impairments and/or asymmetric amplification) but also for users of non-auditory aids, such as tactile aids and cochlear implants, that employ a single input channel. In addition, such achievements are important for development of a coherent, logical approach to the whole spatial diversity question. Without a clear understanding of the benefits and limitations of multimicrophone *monaural* aids, the task of understanding the benefits and limitations of multimicrophone *binaural* aids becomes unnecessarily complex. Furthermore, in order to evaluate the advantages of binaural aids properly, it is necessary to compare these aids to properly chosen monaural aids. If multimicrophone monaural aids (MMAs) can be developed that are superior to conventional monaural aids, then past comparisons of binaural and monaural aids will have to be re-evaluated.

To be effective in complex environments, an MMA should enable the user to (1) focus on signals arriving from a specified direction (and switch the chosen direction rapidly) and (2) monitor and localize signals from all directions. Moreover, it should enable the user to perform these two tasks essentially simultaneously.

The ideal system for performing these tasks (considered abstractly and without regard to human perceptual limitations or hearing-aid constraints) can be outlined as follows. The "front end" of the system would consist of a large sensor array and parallel processing of the signals received at the elements of this array to achieve simultaneous directional channels (i.e., isolated channels, each of which contains only the signals emanating from a particular direction). The "central processor" would then monitor all directions by monitoring all channels of this "directional-filter bank," determine the direction of any signal by noting the channel in which it appears, focus at will on any direction by attending to the associated channel, etc. The key features of this ideal system are the *angular resolution* provided by the sensor array, the *parallel processing* for all directions simultaneously, and the *coding of direction* (achieved in this case by the availability of separate directional channels and the knowledge of which channel corresponds to which direction).

The human binaural auditory system approaches the ideal system to only a limited degree. Not only is the sensor array highly restricted (two ears separated by 16 cm), but, as evident in dichotic listening and selective attention tests, directional coding (achieved primarily by means of the lateralization variable) and central processing are far from perfect.

The effectiveness of the MMAs we develop for impaired listeners will depend upon (1) the degree of angular resolution that can be achieved within the constraints imposed by acceptable geometries for the microphone array and (2) the extent to which an adequate directional coding scheme can be achieved for monaural listening. We expect that angular resolution that is at least comparable to that of the normal binaural system can be realized with an MMA system. However, the extent to which we can develop a directional coding scheme that produces results comparable to those achieved in binaural hearing is unclear.

Our research on resolution has focused on the problem of interference reduction for targets located straight-ahead of the listener and interference sources off to the side (i.e., constructing a single directional filter oriented toward 0°). Our research on directional coding has focused on the use of linear filtering.

INTERFERENCE REDUCTION

We have followed several approaches in using multimicrophone arrays to reduce interference in hearing aids. In the beamforming approach, a directional antenna is formed by modifying the amplitudes and phases of the frequency components of the microphone signals (i.e., weighting the outputs) and summing. In fixed beamforming, the weights are held constant; in adaptive beamforming they are adjusted according to properties of the environment. In other approaches, we have examined systems that attempt to mimic in some restricted way the behavior of the binaural auditory system. One such system temporally gates an output signal dependent on intermicrophone correlation; another simply capitalizes on acoustic head-shadow effects.

The relative usefulness of fixed vs. adaptive beamforming depends on the size of the array measured in wavelengths of the relevant acoustic energy. If the array is large compared to all wavelengths, then it is possible, using classical methods, to form a fixed, narrow, high-gain beam pointing in the desired direction and to achieve enhanced target intelligibility for a wide range of interference configurations. If, as in the hearing aid application, this condition is not satisified, then the situation becomes more complex. In addition to considering the possible benefits of applying supergain techniques in the fixed-weight case [12], one must consider adaptive systems that estimate the characteristics of the background interference and choose weights that are appropriate for those characteristics (i.e., form antenna patterns that "null out" the interference).

Adaptive beamforming

Our research on adaptive beamforming [11] has focused on the constrained adaptive beamforming method of Griffiths and Jim [4]. Constrained adaptive beamformers are based on the assumptions that the target and interference are uncorrelated and that the target direction is known, and operate to minimize total ouput power under the constraint that signals from the target direction are preserved. Minimization of total output power then implies minimization of interference and maximization of target-to-interference ratio. Although the Griffiths-Jim method adapts more slowly than some other methods [1], it asymptotically bounds the performance that can be achieved by any constrained adaptive beamformer and is relatively simple to realize.

A two-microphone version of a Griffiths-Jim beamformer has been studied in three environments with different degrees of reverberation. It is important to determine the dependence of performance on reverberation because the presence of reflected target energy violates the basic assumptions of the method. If one regards the reflected target energy as interference, then the assumption that the target and interference are uncorrelated does not hold. If, on the other hand, one regards it as part of the target signal, then the assumption of known target direction is violated.

Intelligibility tests were performed on normal-hearing subjects using sentences as the target signal and speech babble as the interference. The microphone signals were generated by passing the target and the interference through simulated room transfer functions [10]. It was assumed that the microphones were separated by 20 cm, that the microphones and sound sources were omnidirectional (i.e., the simulation did not include the effects of transducer directivity or head shadow), and that the interference arose from a single source 45° from the straight-ahead target. The simulated rooms were chosen to represent anechoic space (no reverberation), a living room (moderate reverberation) and a conference room (strong reverberation). Intelligibility was measured for three cases: monaural unprocessed (one microphone signal to one ear or, equivalently, the same microphone signal to both ears), binaural unprocessed (one microphone signal to the left ear, the other to the right ear), and monaural processed (the processed single-channel output of the two-microphone system to a single ear or, equivently, to both ears). All system parameters were held fixed except the length of the adaptive filter; preliminary examination suggested that two lengths be tested, 10 ms and 40 ms. Longer filters can potentially remove more interference, but at the cost of more computation and longer adaptation times. In all cases, the intelligibility tests estimated the asymptotic (adapted) performance of the system. Empirical adaptation times, with the given system parameters, were of the order of one second.

The results of these tests, summarized in Table I, indicate that under the given conditions, and with zero-to-moderate reverberation, the interference reduction achieved by the array exceeds that achieved by the binaural auditory system. Furthermore, when the reverberation is severe, the array performance is no worse than that of the binaural system. We are now investigating the generalizability of these results and their implications for a practical hearing aid.

	Anechoic	Living	Conference
Binaural	6	5	1
Monaural-Processed			
10 ms filter	30	9	--
40 ms filter	30	14	1

Table I. Decrease in Target-to-Interference Ratio (dB) required to produce the same intelligibility score as that obtained in the monaural-unprocessed condition in each environment.

Correlation-based gating

Two variants of a processing scheme first proposed by Kaiser and David [7] were evaluated for enhanced intelligibility [9]. In both systems, the running cross-correlation between two microphone signals is used to derive a time-varying gating signal that multiplies the sum of the microphone signals to form a monaural stimulus. With a target source straight-ahead and an interference source off-axis, this processing results in an output that is increasingly attenuated with decreasing target-to-interference ratio. We did not attempt to replicate Kaiser and David's system exactly; our systems differed from theirs with respect to the dynamic behavior of the gating system.

In the first system examined in our study, the processing was applied to the wideband inputs and in the second it was applied independently to four octave bands. Our results on the wideband system, when we use the method of evaluation used by Kaiser and David, confirm their results: interference that is directionally separate from the target is suppressed. However, on direct tests of target intelligibility, the processing showed no improvement. With the four-band system, three degrees of processing (determined by the function relating output attenuation to cross-correlation) were investigated. Intelligibility tests were conducted using sentences as the straight-ahead target and continuous discourse as the off-axis (90° azimuth) interference. Contrary to expectations based on the report of Kaiser and David, in no case was speech intelligibility improved as a result of processing. In fact, intelligibility declined monotonically with the degree of processing. It was surmised that the benefits of removing temporally and spectrally remote interference do not outweigh degradations of the target signal, at least for cases in which the frequency resolution of the system is poorer than that of the ear.

The better-ear aid

Another processing scheme that is based on knowledge of binaural intelligibility advantages is realized in our "better-ear aid". In this aid, as in the multi-CROS aid [5], two microphones are located on opposite sides of the head, the two outputs are fed to a single ear, and the choice between listening to the left microphone signal or the right microphone signal (or the sum of the two) is controlled by switches. Such an arrangement is potentially advantageous because the acoustic headshadow can lead to large differences in signal-to-noise ratio at the two microphones, particularly at high frequencies. We are currently studying the use of head movements to control the switching operation.

DIRECTIONAL CODING

As indicated above, the coding operation is intended to transform the signals carried in the multiple directional channels so that a listener can resolve these signals (and identify their directions) after they are summed and presented to a single ear. In our initial research [2], the coding operation has consisted of linear filtering. Different transfer functions have been assigned to the different channels in such a way that intelligibility scores are roughly independent of which channel is chosen to carry the target message (and which channels carry the interfering messages). Overall performance is measured by the joint intelligibility, i.e., the intelligibility score averaged over a sequence of intelligibility tests in which each talker/channel combination is specified in turn as the target. A given filter configuration is judged to be helpful if the joint intelligibility for this configuration is greater than the joint intelligibility for the reference case in which there is no filtering and all voices are summed in a wideband channel.

Although our results are preliminary, they suggest that, at least for the case of four different talkers speaking simultaneously, joint intelligibility can be improved by the use of differential filtering. For the best filter configuration tested, the joint intelligibility was 39% compared to the wideband reference score of 22%. Some of our results, however, were less positive. For example, tests with two talkers, easy speech materials, and noise masking (to prevent saturation of intelligibility scores) showed no improvement for filtering. Nevertheless, based on all results to date, we believe that judiciously chosen filtering will provide an overall gain in joint intelligibility for many cases likely to be encountered in real environments.

CONCLUDING REMARKS

Our initial results on the exploitation of spatial diversity for the development of improved hearing aids make us optimistic that clear-cut benefits can be obtained. Planned future work includes evaluation of adaptive interference-reduction systems that employ more than two microphones in environments that contain more than one source of interference, study of the correlation-based gating scheme for cases in which the frequency resolution of the processing system exceeds that of the ear, and comparison of the coding effectiveness achieved by filtering to that achieved by other kinds of coding schemes. Finally, we plan to develop wearable versions of the systems that appear promising in our laboratory for use in field evaluations.

ACKNOWLEDGEMENT

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AMBULATORY TESTING OF DIGITAL HEARING AID ALGORITHMS

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ABSTRACT

A portable unit for testing digital signal processing algorithms is described. In addition to serving as a "prototype" hearing aid, the unit collects acoustic descriptions of the listening environment and permits interaction between user and algorithm settings. A description of the system level design, methods of programming and typical resulting data are described. The portable processing unit complements other methods of evaluation and has significantly contributed to our progress in developing improved signal processing algorithms for the hearing impaired.

INTRODUCTION AND BACKGROUND

Over the past decade there has been a resurgence of interest in hearing aid research. A major contributor to this renewed interest is the approaching availability of digital technology. The flexibility and power of digital components create the opportunity to introduce more complex signal processing algorithms and provide true individualization of processing techniques.

This report describes a portable test device and programming system used for fitting and evaluating digital signal processing algorithms. In developing the unit we adhered to several functional design criteria:

a) the unit must be portable, permitting "real world" testing
b) The unit must allow for rapidly changing between algorithms (comparisons)
c) the unit must allow for rapidly switching between parameter settings within an algorithm
d) it must be possible to retrospectively correlate the statistics of the patients' decisions, the algorithm or algorithms' parameter selection, and the environmental acoustics.

The need for portability is a key aspect of our approach. Prior research, and our own experience suggests that well controlled laboratory settings under-represent the acoustic richness of the "real world" listening environment and therefore inadequately exercise the algorithms. Laboratory experiments may under- or over-estimate the "real world" value of a particular algorithm.

One of the philosophies of our approach is that no single algorithm, whether adaptive or not, will prove optimal for all acoustic environments nor for all individuals. Therefore, it is essential that field trials allow the user, not the experimenter, to select the "best" algorithm, and to allow the user to sample widely from acoustic environments in making his or her choice.

Following is a brief description of the embodiment of the above design criteria, how the resulting device can be programmed, and finally examples of the kind of data that can be obtained from the portable processing device.

DESCRIPTION OF THE PORTABLE PROCESSING UNIT

Hardware and system software

The portable processing unit (PPU) is a battery powered digital signal processing (DSP) system packaged in a plastic case measuring 8 in. x 5 in. x 3 in. (see Figure 1). Four AA alkaline batteries are sufficient to power the unit for approximately 7 hours. High level analog input and output signals (1V peak-to-peak max) for this unit are provided by a separate smaller preamplifier box which connects through cabling to a behind-the-ear package containing a wideband hearing aid microphone (Lectret or Knowles) and a Knowles receiver. We have been using four of these PPU/"preamp box" systems to carry out field trials since July 1986.

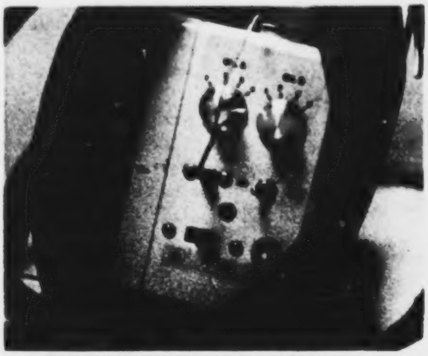

Figure 1. Portable processing unit (PPU).

A block diagram of the PPU device is shown in Figure 2. Two input and two output channels are available, providing the capability for binaural amplification or two-microphone noise canceling. The two output digital-to-analog converters (DACs) can also be connected as shown in Figure 2 to provide an extremely large output dynamic range. Data conversion rates are determined by processor-controlled timers (CK0 through CK5). Signal processing is performed by a CMOS TMS320C10 DSP chip (Texas Instruments). A serial (RS232) interface is used both to download programs to the TMS320 from a host computer, and to offload statistical data obtained during experimentation. The subject controls experimental parameters using two 4-position switches (providing a 4-bit processor input) whose functions are defined by the TMS320. One additional toggle switch, also read by the processor, is used to convey subject preference or event information.

The system is laid out on two boards interconnected by a bus containing data, address, and control lines. The analog board is composed of a power section, two analog input paths, and two analog output paths. The power section provides +5 and -6 volts during normal operation, and a low-current battery back-up for RAM during power off. The input channels contain lowpass

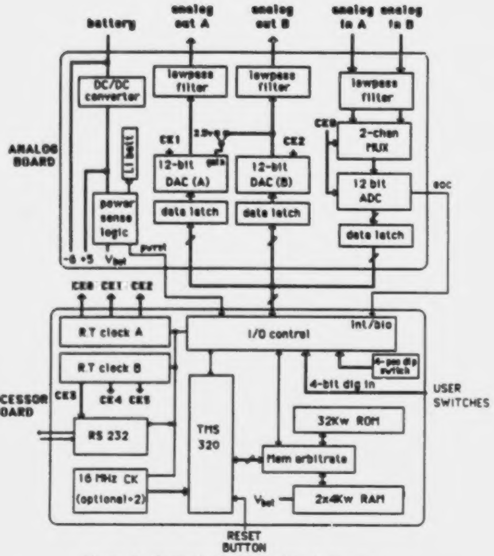

Figure 2. Portable processor block diagram.

(anti-aliasing) filters, and are multiplexed into a single 12-bit analog-to-digital convertor (ADC). Both output channels are composed of 12 bit linear DACs followed by 2-pole anti-imaging filters. Further filtering takes place in the hearing aid amplifiers.

The processor board contains all the DSP and control electronics, the heart of which is the TMS320C10. Depending on the selected operating mode, the TMS320 will execute programs in EPROM (8 Mhz clock cycle) or RAM (16MHz clock cycle). The real-time clocks (A & B), RS232 interface, mode switches, and subject switches are I/O mapped. The EPROM is accessible with I/O instructions at all times, and the RAM can be accessed with I/O instructions when the TMS320 is executing out of EPROM. We have found this level of flexibility to be quite useful.

A 4-bit DIP switch mounted on the processor board determines the mode of operation at power-up or reset. The operating modes include a self-diagnostics mode, a monitor mode for communications with another computer, and up to 14 other "DSP applications" modes. Selecting the diagnostics mode allows the two 4-position user switches to map to 16 different diagnostic settings for testing gain, analog bandwidth, DAC linearity, and overall functionality of the system. Selecting the monitor mode enables communication between the PPU and another computer via the RS232 port. Monitor functions include memory inspection, memory modification, program/data downloading, program/data uploading, and system reset. Each of the 14 possible (EPROM resident) DSP applications is an independent program utilizing up to 4K words of program memory.

Applications and fitting software

In the context of the PPU, an applications program is a collection of signal processing algorithms or steps that provide a desired function. Conceptually, an applications program consists of a program segment containing "code", a parameter segment containing all the variables which can be set during the fitting process, and a "statistics" or data segment which provides space for data which is collected during a given experiment.

Due to the experimental use of the PPU, it was necessary to develop a very flexible software package for programming and fitting. A personal computer is connected to the PPU via the RS232 interface, providing the means to read and write to program RAM using the system monitor described above. The fitting process centers around a "parameter matrix" displayed on the PC screen. This matrix defines the complete "setup" for a given applications program. Each row of the matrix corresponds to one of the 16 user switch settings determined by the two 4-position subject switches. Each column corresponds to a single algorithm parameter such as the gain in a frequency band or level of a compression knee. Therefore, a single element in the fitting matrix is the specific value of single parameter for the related user switch setting. The basic functions of the fitting software are 1) to provide simple and efficient means to modify the individual matrix elements; 2) to provide a means to "save" and "recall" complete setups; 3) to send the selected parameter setup to the PPU; 4) to load applications programs in RAM (when not using EPROM-resident applications); and 5) to "offload" any patient responses and data that results from an experiment. These functions are provided to the operator in the form of cursor operations, single key operations, and two-letter commands followed by arguments.

PROTOCOL RESULTS

Virtually all PPU protocols involve comparisons among digital algorithms or between digital algorithms and a patients' preferred analog system. The former protocols are focused primarily on obtaining information for facilitating DSP algorithm evaluation and development. The latter protocols are used primarily as a means of measuring progress relative to existing technology.

One measure common to both of the above protocols is the acoustic description of the listening environment. The primary acoustic data is represented as shown in Figure 3. The abscissa is a timeline, advancing in one to fifteen second increments, depending upon the protocol. Each sampling epoch results in two values - a maximal and a minimal sound pressure level. The minimal value is assumed to represent the background noise level, in the absence of speech. The maximal value is assumed to represent the speech level, when speech is present. There are significant fluctuations in signal, background noise and signal-to-noise ratio over time. These data can also be represented in histogram form, for assessment of overall levels and SNRs.

A typical distribution of patient switch selections is shown in Figure 4. Note that switch settings 3 and 4 for switch A were never selected and that there is a clear non-random distribution of switch setting combinations. The number of changes of the binary decision switch is expressed as the number of switch toggles. Finally, each

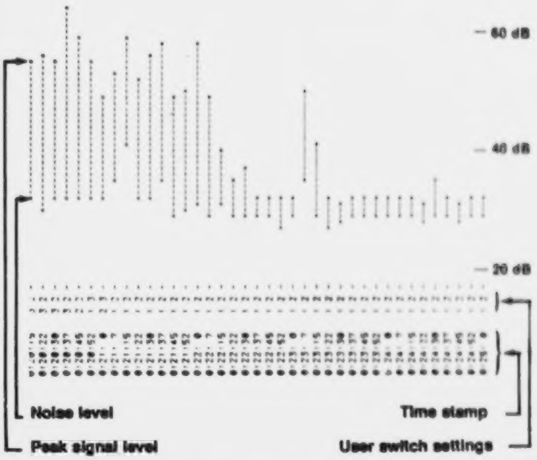

Figure 3. Sample experimental data acquired by the portable unit.

SWA SWB	1	2	3	4
1	5%	51%	0%	0%
2	6%	32%	0%	0%
3	1%	5%	0%	0%
4	0%	0%	0%	0%

Total Number of Toggles: 20

Length of time line: 8:30:30

Figure 4. Patient switch selection matrix.

printout includes the length of the protocol and thus the size of the sample upon which the matrix is calculated.

The patient binary decision switch has had only one application, so far. For all protocols patients are asked to flip the binary decision switch whenever they encounter a sound which is undesirably loud. The number of undesirable events is then compared across algorithms or across models of hearing aids.

Rating scale data is also collected in each clinical setting (e.g. office, home, while riding in the car) and the performance evaluation then related to the environmental acoustics. In general, when subjects are instructed to visit "comparable" settings for comparative trials the acoustic measures suggest that they almost always succeed. The comparability of the acoustic measures across algorithms or models provides additional assurances that the preference behavior is meaningful.

DISCUSSION

The data collected from protocols involving the portable processing unit have had a significant impact on our development efforts. Verification of results from well controlled laboratory experiments, accumulation of statistics on the acoustics of every day listening environments and information on individual differences in algorithm preferences are three areas in which the portable processing units have substantially contributed to our progress.

One of the potentially frustrating aspects of analyzing data from field trials is the lack of control of the acoustic experience across algorithms or individuals. One method of addressing this problem is to require that the histograms of acoustic measures across comparison conditions not differ significantly from one another. While the accuracy of this approach is limited by the resolution of the acoustic sampling process, it represents a previously unavailable method for controlling or matching acoustic experiences outside of the laboratory setting.

A second important use of the acoustic measures is to begin a data base of the distribution of acoustic energy across various environments.

There remain a number of important experimental issues with field trials which require further attention. For example, users are always aware of which device they are wearing. This test system is not portable however. A clear challenge for the future is the development of a portable processing test system which can switch between analog and digital systems without patient knowledge of which aid is in operation.

CONCLUSION

The portable processing unit provides a level of testing flexibility and experimental control not possible with existing instrumentation. The contributions of such test units to the hearing aid development effort are multiple including clinical field trials of candidate algorithms, providing a more detailed description of user behavior with regard to switches and settings and building a quantitative data base of the acoustics of "real world" listening environments.

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SPEECH PERCEPTION WITH AN EIGHT-CHANNEL COMPRESSION HEARING AID AND CONVENTIONAL AIDS IN A BACKGROUND OF SPEECH-BAND NOISE

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ABSTRACT

A multichannel compression hearing aid was developed, implemented with off-line digital signal processing, and tested on twenty subjects with sensorineural hearing loss using speech sounds in a background of speech-spectrum noise. Three listening conditions (multichannel compression aid, conventional aid and unprocessed) were tested at five signal-to-noise ratios (+15 to -5 dB) at two noise levels (60 and 70 dB SPL). Both aids improved speech recognition preformance and the multichannel compression aid produced better performance than the conventional aid. In four subjects with gradually sloping hearing losses, the multichannel compression aid produced near-normal performance even at low signal-to-noise ratios. The results also suggested that learning to use the aid was more important for the multichannel compression than the conventional aid. These results indicate that a multichannel compression hearing aid can be very effective for individuals with sensorineural hearing loss.

INTRODUCTION

Recent work in our laboratory has been directed toward characterizing the suprathreshold auditory function of individuals with sensorineural hearing loss (SNHL) by means of a theoretical model of pitch processing (1)(2). This work has led to the design and testing of a multichannel compression hearing aid in which the model is used to determine the shape of the amplification functions in each channel. The purpose of this report is to compare the performance of the model-defined hearing aid with that of an individually fit conventional aid and with unaided performance in 20 SNHL subjects. The action of all aids in this study was simulated by means of digital signal processing software.

BACKGROUND

In a multichannel compression hearing aid the auditory signal is processed in independent channels, each containing a different frequency band; the amplification varies within each channel such that high intensities in the channel reduce the amount of amplification in that channel, and low intensities in the channel increase the amplification. The advantage of multichannel compression is that a high amplification can be applied to low intensity components of the sound in one channel at the same time that a low amplification is applied to high intensity components in another channel; the hearing aid user thus receives as much as possible of the auditory information contained in the lower intensity components without being exposed to excessively loud sounds. Of course, if high and low intensity components occur simultaneously in the same channel, the higher level component determines the amplification and the lower level component may be lost. The multichannel aspect of the aid reduces such loss of information in comparison, for example, to commercially available single channel wide-band compression systems.

Demonstrating the efficacy of multichannel compression has proven much more difficult than recognizing its potential. In their review, Braida et al. (3) attribute this lack of experimental success to the technical and methodological complexity of the problem. Several of the suggestions of Braida et al. have been incorporated into the present experiments.

METHODS

Volunteers were recruited to participate in this study from local speech and hearing centers and from the community. Three women (S2,S7,S11) and 17 men ages 45-77 years (mean 64 years), with varying degrees of cochlear pathology, completed the study. In some subjects etiologies were unknown; other subjects had familial histories of hearing loss with aging and 16 reported a history of excessive noise exposure.

The test materials consisted of eleven sub-tests of the closed-set CUNY Nonsense Syllable Test (NST) developed by Resnick et al. (4). The male voice stimuli, digitized from prerecorded tape, were filtered into eight bands: six 1/2 octave bands from 750 to 4000 Hz in addition to one above 4000 Hz and one below 750 Hz. For the unprocessed condition, these bands were recombined after filtering while for the processed conditions, the bands were selectively amplified before recombination. For the "conventional" aid, amplification within bands was a linear constant which varied across bands to match the frequency response of the professionally fit, commercially available hearing aid. Peak clipping or compression was done after recombination to complete the "conventional" aid. For the "model" aid, amplification within bands was a function of the signal level determined individually with the model (1)(2) and implemented in a way similar to Robinson and Huntington (5). Speech spectrum noise (SSN), random noise shaped to the average speech spectrum, (duration 1 sec.) was added to the speech signal prior to the processing that corresponded to the aids.

The 91 syllables of the NST were randomized, independently for each run, and presented monaurally to the subjects who responded to the 7 to 9 response foils for the sub-set appropriate for the particular stimulus. Test signals were computer generated and delivered through a Danavox SM-W wide-band receiver coupled to the subject's earmold or a TDH-39 earphone in a circumaural cushion. All testing was done in a single-walled IAC booth. Prior to stimuli in noise, each subject ran at least 100 runs of processed and unprocessed speech sounds without noise. These "quiet" sessions served primarily as training--all aids tested worked well in quiet.

There were three hearing aid conditions at each signal-to-noise ratio (S/N): (a) "unprocessed," (b) "conventional" aid and (c) "model" aid. Two noise levels (60 & 70 dB SPL) each included five S/N values (15, 10, 5, 0, & -5 dB). Thus, the speech sounds covered the range from soft (55dB SPL) to loud (85dB SPL) speech. Within each S/N at each noise level, 5 runs of 91 syllables for each condition were done in random order, so that any learning effects would be distributed equally across aids.

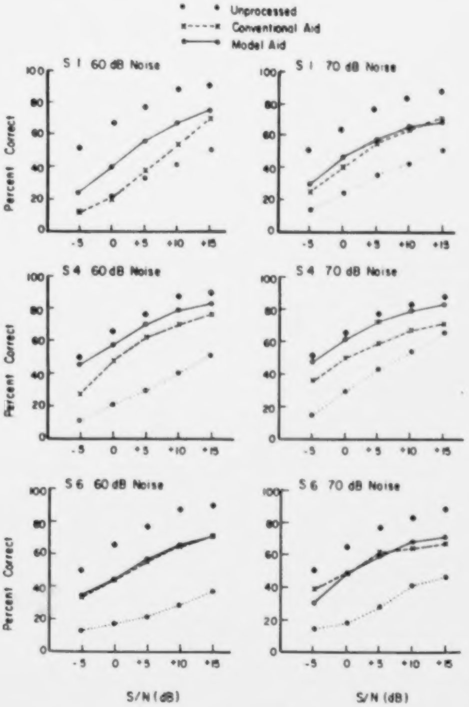

Figure 1: Results for S1, S4 and S6.

RESULTS

Due to space limitations, the results of only three of the twenty subjects will be presented here in detail; complete data is presented elsewhere (6). Fig. 1 illustrates the performance of each of the three subjects under all of the experimental conditions tested. Each of the six panels of Fig. 1 shows the data from one subject (S1, S4 and S6 in the upper, middle and lower rows, respectively) at one noise level (60dB on the left and 70dB on the right). Within each panel, the percent correct is plotted on the ordinate with the signal-to-noise ratios (S/N) on the abscissa. Each data point in the figure represents a mean of five repeats of the 91 item list for each subject at each S/N. The filled circles represent the "unprocessed" condition; the open circles and X's represent the "model" and "conventional" aids. The unconnected diamonds are normal-hearing performance with the unprocessed stimuli. Two subjects, S4 & S6, come from the group with more gradually sloping audiograms and the third, S1, comes from the group with steeper sloping audiograms.

Several points should be noted in the data of Fig. 1: (a) Each panel reveals a considerable deficit in the ability of the SNHL subject to recognize speech sounds in noise; the unprocessed curve (filled circles) is far below the "normal-hearing" diamonds. (b) Both the conventional aid and the model aid improve performance. (c) Both the absolute and the relative positions of the curves for the two types of aids varies within and across subjects; S6 performed equally well with the two aids, as did S1 at 70dB noise, but S4 and S1 at 60dB noise performed much better with the model aid. (d) The model aid produced the nearest-to-normal performance in any SNHL subject; data of S4 was included in Fig. 1 to illustrate that very high level of performance, but the SNHL subjects with the next three nearest-to-normal performances also achieved that very high level of performance using the model aid.

Data from all 20 subjects are summarized in Table I in a highly processed form: we have quantified the hearing loss, and the residual loss after correction by the aids, on a linear scale of 0 to 100, where a loss of 0 represents normal-hearing performance and a loss of 100 represents chance performance at all S/N tested. Since the loss for the unprocessed condition was very similar at the two noise levels, they were combined for the "Loss" column of the table. Losses for our subjects vary from a minor impairment of 20 for S7 to a major impairment 92 for S10. These values mean that S7 would fail to recognize only 20 out of 100 syllables correctly recognized by normal-hearing subjects, but that S10 would fail to recognize 92 of 100 such syllables. The other four data columns in the table indicate the residual loss with the conventional and the model aids at 60dB and at 70dB SPL SSN. The values in these columns have the same meaning: the value 15 at the top of the far right column means that, using the model aid at 70db SPL SSN, subject S2 would miss only 15 of 100 syllables recognized by normal-hearing subjects. In Table I, the subjects are divided into three groups, those with more gradually sloping audiograms (e.g. S2, S4, S6), those with steeply sloping audiograms (e.g. S1) and those with other types of losses (e.g. S7). Mean values within sub-groups and the overall means are included. An analysis of variance on the data of Table I indicates that, overall, the model aid performed significantly better than the conventional aid ($p<.05$). It also can be seen in Table I that the mean residual loss is lower for the model aid than for the conventional aid in each group at each noise level and that the seven lowest residual losses were obtained with the model aid (S4-70dB, S4-60dB, S15-60dB, S17-60dB, S17-70dB, S2-70dB and S2-60dB).

Table I: Unaided & Residual Aided Hearing Loss

		60dB SPL SSN		70db SPL SSN	
Subject	Loss	Conv	Model	Conv	Model
S2	50	27	15	31	15
S3	69	41	34	38	35
S4*	64	30	11	30	8
S6*+	78	32	32	28	29
S9	79	34	37	48	50
S14	37	19	21	39	41
S15*+	67	22	11	18	19
S17	61	18	11	17	12
S18*+	73	56	41	60	58
S19*	91	62	62	57	72
Mean	67	34	28	37	34
S1	69	60	36	37	34
S5	73	69	60	73	60
S10*	92	76	76	80	78
S13*+	71	33	33	37	31
S20*	79	61	57	63	69
Mean	77	60	52	58	54
S7	20	30	19	43	29
S8	49	36	48	49	50
S11*+	78	49	43	47	40
S12*+	67	58	42	54	51
S16*+	78	36	47	47	58
Mean	58	42	40	48	46
Overall	67	42	37	45	42

* = Hearing aid user.
+ = Conventional aid like subject's own.

DISCUSSION

The present results suggest two major questions for discussion: (A) Why is our multichannel compression hearing aid successful when other such aids appear to have failed? (B) Why is our aid so much more successful in some subjects than in others? Space permits only brief consideration of possible answers.

The present experiments differ from previous experiments with multichannel compression hearing aids in many details of experimental methods as well as the design of the aid. No other experiments have used as many subjects, as wide a range of speech and noise intensities, or the unaided-SNHL and the normal-hearing data against which to evaluate the performance of the aids. Previous multichannel compression aids might have appeared much more successful than they did had they been similarly tested.

The design of our multichannel compression hearing aid was based upon previous work in our laboratory concerning the processing of pitch information in normal hearing subjects. One stage of a model developed to explain the pitch effects, corresponds to the cochlear hair cells and methods were developed to measure the "response" of that stage as a function of stimulus intensity. Such measurements in our SNHL subjects were used to determine the shapes of the compression functions used in the various channels of our hearing aid. Virtually all of the other parameters of our aid also differ from other such aids, e.g., the method of compression, the time constants, and the size, number and position of the frequency bands. The shapes of the compression functions or the values of any of these other parameters could be critical to the operation of the aid.

In terms of the differences among subjects, there is a similarly large range of possibilities. Different subjects may need different time and/or frequency parameters in the aid. Alternatively, in a hearing loss where considerable signal distortion occurs, the increased information content of the compressed signals may be detrimental; S16 displayed more binaural diplacusis than any other subject and was the only subject for whom the model aid was consistently less successful than the conventional aid. We have also noted a pattern in the results of some subjects: they achieved better performance with the model aid in whichever noise level they ran second. Other details of the results also suggest that learning to use the model aid may be very important. Only further work will clarify these issues.

CONCLUSIONS

These results establish that a multichannel compression hearing aid can be very effective. In addition, the initially successful version of the aid provides a valuable basis upon which an even more effective multichannel compression hearing aid may be developed.

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EXPERIMENTS WITH A TWO-CHANNEL COMPRESSION-LIMITING AMPLIFICATION SYSTEM DESIGNED FOR PROFOUNDLY DEAF SUBJECTS

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ABSTRACT

Using a 2-channel Master Hearing Aid with adjustable compression-limiting, the perception of 8 speech contrasts was measured in 9 profoundly deaf subject under 2 amplification conditions: a) Equalization Only, in which the outputs of the two channels were adjusted for highest comfortable level, and b) Equalization plus Compression, in which an input range of 30dB was compressed into the hearing range of the subjects. One subject showed significant improvements with compression, but the remaining 8 showed wither no change or a small decrease of score.

INTRODUCTION AND PURPOSE

Among the profoundly deaf, most retain some auditory function. It is difficult, however, to provide these individuals with suitable amplification. There are several reasons, one of them being their limited dynamic range of hearing between the thresholds of audibility and discomfort. This range is typically less than the 30dB minimally required to encompass the range of intensities in the speech signal. It has often been suggested that this problem can be overcome with the use of fast-acting amplitude compression <1>. The profoundly deaf, however, rely heavily on the amplitude envelope of speech to obtain what little help they can from audition in the perception of speech <2>. Amplitude compression, by definition, distorts the amplitude envelope of the acoustic signal. It is quite possible, therefore, that it could reduce speech perception performance rather then enhance it. In a previous study, using a single channel compression system, one out of 10 subjects did, indeed, perform less well when compression was introduced <3>.

If we wish to measure the effects of a change of amplification characteristics on speech perception, we must use a speech perception test. Most such tests presuppose that the subject is familiar with the acoustic properties of spoken language. They often assume a normal vocabulary, and may also require reading skills. Subjects with prelingually acquired profound deafness are typically deficient in all three areas. This creates serious problems for the researcher who wishes to study the amplification needs of this population.

The purpose of this study was to test the hypothesis that reduction of the dynamic range of the speech signal by means of a fast-release compression limiter would enhance the perception of speech by the profoundly deaf. The problem of measuring instrument was adressed by the development of a new test that does not require the subject to have phonological, lexical, or reading skills.

SUBJECTS

Nine profoundly deaf subjects took part in this study. All losses were acquired prelingually. Ages ranged from 11 through 16 years. Only one ear was used for testing. The criteria for selection were, in order of priority, the aided ear, the preferred ear, the ear with the lower average threshold, and random selection.

AMPLIFICATION

A two-channel master hearing aid, with adjustable compression limiting (see Figure 1.), was used to establish two amplification conditions. The first was Equalization Only (EO), in which the outputs of the two channels (70 to 1KHz and 1K to 7KHz) were independently adjusted to highest comfortable level. The second was Equalization plus Compression (EC) in which the prelimiting gains in the two bands were independently increased so that a 30dB input range was compressed into the dynamic range of hearing of the subject. The release time of the compression limiter was set to 20 msec. It could, therefore, recover within the time typically occupied by a single speech sound and reduce the short-term dynamic range of the signal.

SPEECH TEST

The ability of subjects to perceive phonologically significant speech pattern contrasts was assessed using a 3-interval, forced-choice test (THRIFT) in which the subject's only task is to identify the odd-man-out in three, sequentially presented syllables <4>. The test evaluates 10 contrasts: two suprasegmental (DURation and INTonation); two Vowel (Height and Place); and six Consonant (Voicing, Continuance, and Place, in Initial and Final position). There are 24 trials for each contrast, the phonetic context changing from trial to trial. For the present study, the final consonant continuance and place subtests were omitted in the interests of time.

PROCEDURE

After confirming that a subject was free from middle ear infections, Speech Awareness Threshold and Highest Comfortable Level were determined for both high and low channels, using a synthetic vowel /a/. These data were used for setting the EO and EC conditions for speech testing. Performance on each of the eight test contrasts was then measured twice under each of the two amplification conditions.

RESULTS

In an initial analysis, replication was not found to be significant, either as a main effect or in interaction with other variables. Results were, therefore, collapsed across replication.

Figure 2 shows, for each subject, the difference in score between the EO and the EC conditions for each of the contrasts tested. Significant changes, as determined in a simple 3 way analysis of variance, are shown in black. It will be observed that only one subject, J10M, experienced a significant improvement on several contrasts, when compression was introduced. Subsequent testing confirmed that performance fell when compression was removed. Among the remaining subjects, however, the tendency was for no change, or a slight deterioration when compression was introduced. Included in Figure 2 are the group mean data for these 8 subjects (i.e., excluding J10M). In an analysis of variance, the interaction between subject and amplification condition was not found to be significant for these eight subjects. There was, however, a significant interaction between subject and contrast. It will be seen that the greatest effect was in the score for vowel height. The only other contrasts showing a significant effect were final consonant voicing and initial consonant continuance.

DISCUSSION AND CONCLUSIONS

These data provide conflicting results. In one subject, the increase of access to the acoustic spectrum, made possible by amplitude compression, had a beneficial effect. In the other 8 subjects, however, the tendency was for no change, or a small reduction of performance. The fact that this reduction was greatest for vowel height, a contrast that is accompanied by amplitude changes, supports the notion that the cause of the negative effect was distortion of the amplitude envelope.

Bearing in mind that these results were obtained with isolated syllables, and may not, therefore, be applicable to the perception of connected speech, we may tentatively conclude that amplitude compression is by no means necessary or desirable for all profoundly deaf subjects, but may be beneficial in individual cases.

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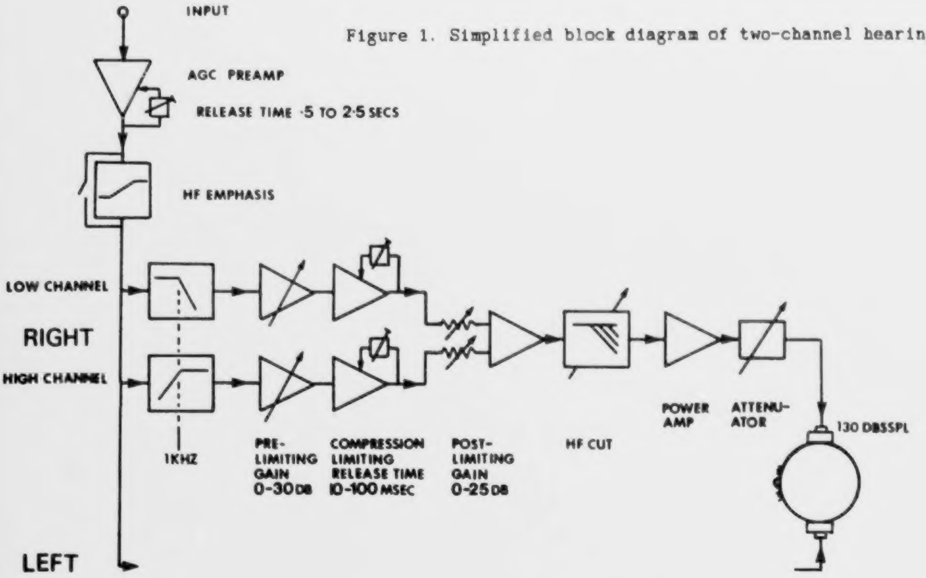

Figure 1. Simplified block diagram of two-channel hearing aid.

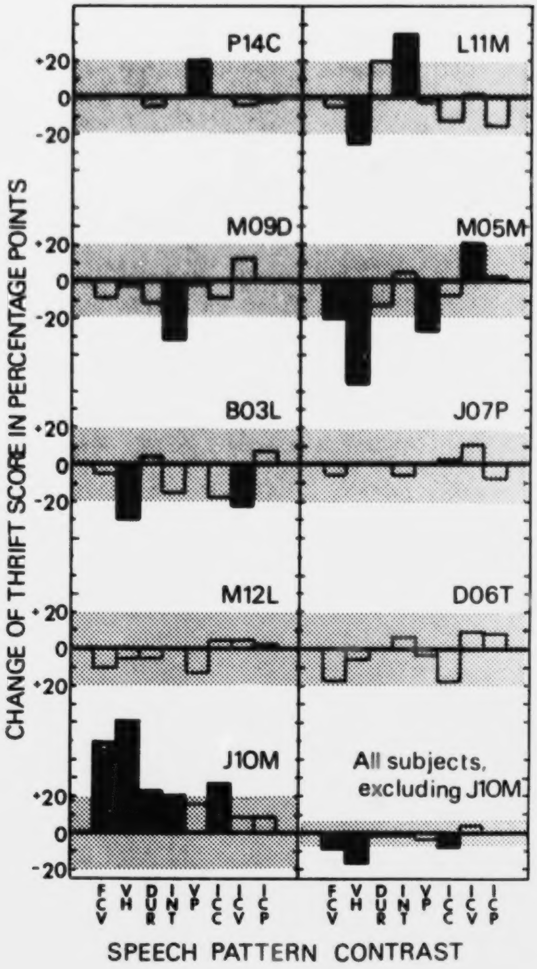

Figure 2. Changes of THRIFT score resulting from the introduction of amplitude compression. Data are shown for 9 subjects and 8 contrasts. Also shown are the mean data for 8 subjects, i.e., excluding the one subject, J10M, who showed significant benefit from compression. Significant changes ($p<.01$) are shown by the solid bars. See text for explanation of contrasts.

DISCRIMINABILITY OF FREQUENCY-RESPONSE IRREGULARITIES IN HEARING AIDS

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ABSTRACT

A digitally controlled hearing aid measurement and simulation system was used in experiments to measure the sensitivity of normal and hearing-impaired listeners to frequency response irregularities in hearing aids. The system was first used to measure frequency response irregularities in typical hearing aids. The data from these measurements were used to select the variables for the perceptual experiments. The system was then used to simulate hearing aids with irregularities in their frequency responses. The detectability of single and multiple peaks in the frequency response was measured. For normal hearing listeners, average peak detection thresholds were roughly 6dB for single peaks and 3dB for multiple peaks. For hearing-impaired listeners the corresponding peak detection thresholds were roughly 11dB and 6dB, respectively.

INTRODUCTION

The frequency response of a hearing aid typically contains a number of peaks and valleys which are referred to as frequency response irregularities. It is expected that hearing impaired listeners will be able to detect the presence of frequency response irregularities, and in addition, will prefer a frequency response without these irregularities. Several studies have demonstrated that speech recognition performance with an irregular frequency response is affected adversely (1,2,3). What is not indicated from the above studies is the type and degree of frequency response irregularity that affect listener performance. One of the limitations of past investigations was the use of commercial hearing aids to generate response irregularities. Commercial hearing aids do not provide sufficient flexibility and control to investigate the parameters of response irregularity. Computer controlled hearing aids offer a solution to this problem in that the characteristics of a hearing aid can be manipulated efficiently and precisely in real-time.

MATERIALS AND METHODS

A digitally controlled hearing aid measurement and simulation system, the Chameleon, was used in experiments to determine the sensitivity of normal and hearing-impaired listeners to frequency response peaks. Details of the Chameleon are described in Levitt et al. (4). The approach taken in this study was to first specify the characteristics of frequency response irregularity that are typical of commercial hearing aids with standard tubing and earmold coupling. Next, experiments were conducted to measure the detection of typical response peaks.

The Chameleon was used in its hearing-aid measurement mode of operation to obtain the manikin frequency responses of 35 commercial hearing aids (5). Each hearing aid was placed on the manikin's pinna and coupled to the manikin ear canal extension with an occluding earmold. The tip of the earmold terminated at the junction between the occluded-ear simulator and the ear-canal extension. Tygon tubing with a length of 43mm and an internal diameter of 2mm was used to couple the hearing aid to the earmold. The frequency response of each hearing aid was obtained with the gain set to the reference test position (6). These response curves were stored on floppy disk for subsequent analysis.

The irregularities of each frequency response curve were specified in terms of the number of response peaks and the height, center frequency, and bandwidth of each peak. A peak was defined as an irregularity with a ratio of greater than 3dB between an adjacent maximum (peak) and minimum (valley). Peak height was defined as the difference in dB between an adjacent peak and valley. The peaks were then classified into groups according to their center frequency. Standard one-third octave band categories were used. The bandwidth of each peak was specified as the difference between the two 3dB points, i.e., the frequencies on either side of the peak at which the response was 3dB down identified the upper and lower frequency bounds of the peak.

An analysis of the sample hearing aids revealed that these hearing aids have a number of peaks in their frequency response, typically between 4 and 6. The peaks occur over a wide frequency range but tend to be concentrated in the high frequencies. Peak height ranged from 3 to 22dB with roughly half of the peaks having a peak to valley ratio of 3 to 5dB. Peak bandwidth varied with center frequency and in most cases exceeded the critical band for normal hearing listeners.

Frequency-Response Irregular.

The above data were used to select the characteristics of frequency response irregularity to be varied in two experiments. This procedure insured that the results of the experiments could be generalized to typical hearing aids. The Chameleon was used in its simulation mode of operation for the perceptual experiments.

Experiment 1 -- The purpose of this experiment was to find the sensitivity of normal-hearing subjects to a single-peak and multiple peaks in the frequency response curve. The detectability of a single peak was obtained as a function of peak frequency (1.0 and 3.15 kHz). The detectability of multiple peaks (peak center frequencies at four frequencies; 1.0, 2.0, 3.15, and 4.0 kHz) was obtained as a function of signal level (60dB and 75dB SPL), and time order (measurement 1 and measurement 2).

An AXB paradigm was used to obtain peak detection thresholds. Subjects were required to switch between three frequency responses A, X or B; frequency response X being the same as either A or B. Frequency response A consisted of a reference frequency response and response B consisted of a peak superimposed on the reference frequency response. The reference frequency response and test frequency response were assigned randomly to channels A and B on each trial. Subjects listened to continuous discourse in noise and were instructed to judge whether X was different from A or B. Peak height was varied using a transformed up-down adaptive strategy to estimate the 70.7 percent point on the psychometric function for peak detection threshold (7).

RESULTS

The average Peak Detection Threshold obtained for a single peak was 5.5dB. A repeated measures analysis of variance showed no significant effect for Frequency. The average Peak Detection Threshold obtained for multiple peaks was 3.0dB. There was a small but significant effect ($p<.05$) for Signal Level. The Peak Detection Threshold at 60dB SPL was 3.4dB, whereas at 75dB SPL, the Peak Detection Threshold was 2.6dB.

Experiment II -- The purpose of this experiment was to find the sensitivity of hearing-impaired subjects to both single peak and multiple peaks in the frequency response curve. Subjects were six hearing-impaired adults (mean age = 70 years) with sensorineural hearing loss (PTA = 44dB HL) and a minimum of one year of hearing aid use.

Peak Detection Thresholds were obtained using the three-interval forced-choice discrimination task described in Experiment I. The detectability of a single peak in the frequency response was obtained as a function of frequency (1.0, 2.0, 3.15, and 4.0 kHz), and signal level (60dB SPL, 70dB SPL). The detectability of multiple peaks was obtained as a function of signal level (60dB SPL, 70dB SPL). For the hearing impaired subjects, the reference frequency response in the AXB paradigm was prescribed individually. Individual prescription was necessary to insure that speech signals were within the subject's range of residual hearing.

RESULTS

The average Peak Detection Threshold for single peaks was 10.8dB. A repeated measures analysis of variance of the single peak data showed a significant main effect ($p<0.05$) for Subjects. Average Peak Detection Thresholds ranged from 8.2 to 14.1dB. The average Peak Detection Threshold for multiple peaks was 6.3dB. Inter-subject differences were significantly smaller for the multiple peak conditions than for the single peak conditions. Whereas multiple peak thresholds ranged from 5.3 to 8.2dB as a function of subject, single peak thresholds ranged from 8.2 to 14.0dB.

A summary of the results from Experiments I and II appears in Table 1.

SUMMARY

The frequency responses of typical hearing aids were found to have multiple peaks that ranged in height from 3dB to 22dB. Approximately half of the peaks had a height of 3 to 6dB and the majority had center frequencies between 1000 to 4000 Hz. Both normal and hearing-impaired subjects were found to be sensitive to these frequency response peaks. Normal-hearing subjects exhibited greater sensitivity than hearing-impaired subjects. The detection threshold for a single peak was roughly 6dB for normal-hearing subjects and 11dB for hearing-impaired subjects. The corresponding thresholds for multiple peaks were roughly 6dB and 3dB for normal-hearing and hearing-impaired listeners, respectively. As a general rule, hearing impaired listeners will detect single peaks greater than 11dB and multiple peaks greater than 6dB.

Frequency-Response Irregular.

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Table 1. Average Peak Detection Thresholds for Experiments 1 & 2.

NORMAL HEARING LISTENERS
SINGLE PEAK EXPERIMENT

Peak Center Frequency (kHz)	1.0	3.15
Average Peak Detection Threshold(dB) (A.P.D.T.)	5.0	6.0

Subject #	1	2	3	4	5	6
A.P.D.T.(dB)	4.3	8.0	6.5	3.8	5.0	5.5

GRAND MEAN = 5.5dB

MULTIPLE PEAK EXPERIMENT

Signal Level	60dB SPL	75dB SPL
A.P.D.T.(dB)	3.4	2.6

Time Order	Measurement 1	Measurement 2
A.P.D.T.(dB)	3.1	2.9

Subject #	1	2	3	4	5	6
A.P.D.T.(dB)	2.9	4.0	3.4	2.3	3.0	2.4

GRAND MEAN = 3.0

HEARING IMPAIRED LISTENERS
SINGLE PEAK EXPERIMENT

Peak Center Frequency(kHz)	1.0	2.0	3.15
A.D.P.T.	10.9	10.5	10.8

Signal Level	60dB SPL	70dB SPL
A.D.P.T.(dB)	11.0	10.5

Subject #	1	2	3	4	5	6
A.D.P.T.(dB)	10.3	13.2	9.2	14.1	9.6	8.2

Grand Mean = 10.8

MULTIPLE PEAK EXPERIMENT

Signal Level	60dB SPL	70dB SPL
A.D.P.T.(dB)	6.6	6.0

Subject #	1	2	3	4	5	6
A.D.P.T.(dB)	6.0	8.3	5.3	7.8	5.3	5.3

GRAND MEAN = 3.0

Orthogonal Polynomial Compression Amplification for the Hearing Impaired

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ABSTRACT

A digital master hearing aid was used to compress speech using the method of orthogonal polynomials. The short-term speech spectrum was first approximated by an orthogonal polynomial expansion and each term in the expansion was compressed independently. The modified short-term spectrum was then transformed back to a timewave form. Compression of the constant term is analogous to conventional compression. Compression of the second term compresses the slope of the spectrum, compression of the third term compresses the curvature and so on. Data obtained on hearing-impaired listeners show a large improvement with compression for low imput levels.

Multiband amplitude compression is an intuitively appealing approach in that it places more of the speech spectrum in the subject's residual hearing area. Experimental evaluations of the technique, however, have yielded mixed results (1, 2, 3). One reason for the relatively poor performance of multiband amplitude compression systems is that because the signal in each frequency band is compressed independently of the signals in neighboring bands, the overall shape of the speech spectrum is severely distorted, thereby destroying those speech cues associated with spectrum shape. Orthogonal polynomial compression controls the amount by which spectrum shape is distorted and thus allows for a systematic evaluation of the effect of changes in spectrum shape in amplitude compression systems. Since the technique is computationally concise the processing can be accomplished in real time.

A digital master hearing aid configured around a MAP 300 array processor was used to process the signals. The speech signal was sampled at 12 kHz and then subdivided into successive sequences of 512 points (corresponding to successive time windows of 42.7 msec) for subsequent processing. The waveform within each time window was subjected to a fast Fourier transform (FFT) in order to obtain the short-term spectrum. The logarithm of the power spectrum was obtained and then approximated by an orthogonal polynomial expansion, as discussed shortly. The coefficients of the polynomial expansion were compressed and the modified power spectrum was converted back to a time waveform.

In order to avoid transients in connecting the waveforms between successive time windows, an overlap-add procedure was used. Two overlapping sequences of time windows were processed independently and then added after reconstruction of the processed time waveforms. The windows overlapped by 50% so that the junction between successive time windows in one sequence of windows occurred midway during a window of the second sequence.

A key stage in the processing is the orthogonal polynomial analysis. The first step is to derive the orthogonal polynomial expansion of the short-term log power spectrum:

$$Li(fj) = B0i + B1i.P1(fj) + B2i.P2(fj) + \ldots. + B(N-1)i.P(N-1)(fj) \qquad (1)$$

where

$Li(fj) = 10.\log[Si(fj)]$ is the logarithm of the short-term power spectrum $Si(fj)$. A multiplicative constant of 10 is used in order to convert to a decibel scale,

the suffix i identifies the time window i,

the spectrum is discrete and is specified at frequencies fj where $j = 1,2....,N$ for a time window of size 2N,

$Pk(fj)$ is the orthogonal polynomial of degree k specified as a function of frequency fj, and

Bki are the coefficients of the orthogonal polynomial expansion for time window i. The coefficient $B0i$ is referred to as the constant, $B1i$ as the linear coefficient, and $B2i$ as the quadratic coefficient.

The coefficients Bki are derived as follows:

$$Bki = \sum_j [Li(fj).Pkj(fj)]/Dk \qquad (2)$$

where

$$Dk = \sum_j [Pk(fj)]**2$$

Note that the denominator in Equation 2, Dk, is a constant and that the derivation of each coefficient involves no more than a single vector operation.

If the orthogonal polynomial expansion of Li(fj) is truncated; i.e., less than N terms are used in Eqn (1), then an approximation to Li(fj) is obtained. In this study, only three terms were used; i.e.,

$$\hat{Li}(fj) = B0i + B1i.P1(fj) + B2i.P2(fj) \qquad (3)$$

The difference between the original and approximate spectra is the error term,

$$Ei(fj) = Li(fj) - \hat{Li}(fj) \qquad (4)$$

A very useful property of the orthogonal polynomial expansion is that, since the polynomials are orthogonal to each other, eliminating any term in the expansion for Li(fj) (Equation 1) increases the error Ei(fj) independently of the remaining terms in the expansion. Further, the increase in Ei(fj) obtained by eliminating a term in Equation 1 is the minimum increase in a least squares sense; i.e., [Ei(fj)]**2 is a minimum for each set of terms eliminated from Equation 1.

The coefficients Bki will vary with i depending on the variation with time in the shape of the short-term log power spectrum. In order to reduce the range of variation, the short-term log power spectrum is modified as follows:

$$\hat{CLi}(fj) = [(1-K0).B0i-B0] + [(1-K1).B1i-B1].P1(fj) + [(1-K2).B2i-B2].P2(fj) \quad ....(5)$$

where

$\hat{CLi}(fj)$ is the compressed approximated short-term log spectrum,

Kk are coefficients of compression (k = 0,1,2), and

Bk are the saturated values of the constants Bki.

For example, if the Kk are zero, no compression will take place. If the Kk are 1 then each term in the expansion will be set to its saturated value.

In this study, Li(fj) was approximated using only the constant, linear, and quadratic terms (See Equation 3). B0 was set equal to the rms value of B0i averaged over many windows (i.e., for i = 1 to M, where M is large). Both B1 and B2 were set to zero. After compression, the compressed estimate of the spectrum $\hat{CLi}(fj)$ was compared to the uncompressed estimate $\hat{Li}(fj)$. The differ-ence between the two estimates identifies the compression characteristic.

$$Ci(fj) = \hat{Li}(fj) - \hat{CLi}(fj) \qquad (6)$$

Where

Ci(fj) is the compression characteristic for window i.

The compressed short-term power spectrum is obtained by dividing the original short-term power spectrum by the antilog of the compression characteristic,

$$CSi(fj) = Si(fj)/Ri(fj) \qquad (7)$$

where

CSi(fj) is the compressed short-term power spectrum, and

$$10.\log[Ri(fj)] = Ci(fj)$$

The most time consuming operations in the above analysis are the fast Fourier transforms used in obtaining the short-term power spectrum and subsequently converting back to the time waveform. The next most time consuming operation was the derivation of the polynomial coefficients (Equation 2). The array processor is well suited for computations of this type and the processing was implemented in real time.

An experiment was performed in which 8 subjects were tested. All were adults with sensorineural hearing loss. An adaptive paired-comparison test procedure was used to find the optimum combination of compression coefficients K0, K1 and K2 for each subject. Speech recognition scores were then obtained for each of three speech levels, 55, 70, and 85 dB SPL for four compression conditions; 1) no compression, 2) short-term power compressed; i.e., B0i only was compressed, 3) short-term power and average slope compressed; i.e., B0i and B1i compressed, and 4) short-term power, average slope, and average quadratic curvature compressed; i.e., B0i, B1i, and B2i compressed. The results showed a substantial improvement in test scores for the lowest speech input, the condition under which compression is most effective. This result was obtained for all three compression conditions.

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Evaluation of Noise Reduction Techniques for Hearing Aids

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ABSTRACT

The use of a hearing aid in noisy environments is one of the most difficult tasks for hearing-impaired listeners. In the past, noise reduction for hearing aids has been almost exclusively limited to high pass filtering. Recent advances in digital signal technology allow for sophisticated forms of noise reduction to be used which could not previously be implemented in conventional hearing aids. Several methods of noise reduction are currently being evaluated. These include both single and two microphone noise reduction techniques. Of the methods evaluated, the two microphone system appears to be the most promising, although there are practical constraints involved in its use. Results of the evaluations of each of the methods will be discussed.

INTRODUCTION

The use of a hearing aid in noisy environments is one of the most difficult tasks for hearing-impaired listeners. In the past, fixed high pass filtering was the major method used to reduce background noise. This method was often unsatisfactory because it resulted in an amplified signal of unacceptable quality; further, only a portion of the background noise was removed.More recently, "automatic signal processing" hearing aids have been designed in which the characteristics of the hearing aid frequency response change with changes in the level of low frequency energy (1).

Recent advances in digital signal technology allow for sophisticated forms of noise reduction to be used which could not previously be implemented in conventional hearing aids. A combination analog/digital circuit which implements a self adaptive noise filter is now available in commercial hearing aids (2). Initial evaluations with a prototype of this system revealed significant improvements in the speech discrimination scores (monosyllabic words) of hearing-impaired listeners in several different types of background noise (3).

While the noise reduction systems employed in commercial hearing aids utilize a single microphone, experimental systems in which the signal from two or more microphones are processed to reduce noise may prove to be more helpful for hearing-impaired listeners. Chabries et al. (4), have demonstrated the usefulness of the Widrow adaptive filter for hearing-impaired listeners when a reference sample of the noise is available in order to allow for adaptive noise cancellation.

In our laboratory, we have been evaluating a number of noise reduction techniques. An evaluation of the Wiener filter technique and of a practical implementation of the Widrow adaptive filter (5) will be described.

EVALUATION OF NOISE REDUCTION SCHEMES

A. Evaluation of the Wiener-filter technique

A Wiener filter is one that minimizes the rms level of the noise at its output. Its frequency response is determined by the ratio of the power spectrum of the signal to the power spectrum of the signal plus noise. In the present study, we examined the effect of Wiener filtering on the identification of consonants contained in nonsense syllables. Consonant recognition for speech presented in a background of cafeteria noise (10 dB S/N) was compared to consonant recognition after processing through an appropriate Wiener filter.

Test stimuli were syllables taken from the original recordings of the NST. Only subsets containing the vowel /a/ were included for testing. This resulted in four subsets, each subset was of CV or VC construction. Voiced and voiceless consonants were placed in separate subsets.

A Wiener filter was calculated for each consonant phoneme in each test syllable based on measurements made of the average power spectrum of each test phoneme and of the competing noise. Test tapes were then made in which the appropriate phoneme filter was used for the nonsense syllable containing that phoneme. For example, the Wiener filter for the final /s/ phoneme would be used for the nonsense syllable /as/ and the Wiener filter for the initial /s/ phoneme would be used for the nonsense syllable /sa/. Ten randomizations of the four subsets were generated.

Six listeners with sensorineural hearing loss served as subjects. Subjects were tested in sevenal test sessions. In the first session the subject's most comfortable listening level (MCL) was established and he was familiarized with the test materials. All subsequent testing was done at the subject's MCL.

A mean score was calculated for the NST based on the ten replications of each test condition. The mean scores for each of the subjects appears in Table 1. A separate analysis of variance was done for each subject to determine whether or not the Wiener filtering caused a significant improvement in performance. For three of the six subjects (Subjects 1, 4, and 5), filtering resulted in significantly better NST scores ($p<.05$).

B. Evaluation of the Widrow adaptive filter.

To implement the Widrow algorithm two microphones are needed. One microphone (primary microphone) is used to pick up speech plus noise. The second microphone (reference microphone) picks up primarily the noise. The output of the reference microphone is fed to an adaptive filter which is adjusted iteratively until the difference between the filter output and that of the primary microphone is minimized. This technique should cancel the noise if the reference microphone picks up noise only.

Previous work by Chabries et al. with hearing-impaired subjects has established the potential usefulness of the Widrow filter. But the method used to implement the filter would be impossible to achieve in a practical hearing aid.

Implementation in a practical hearing aid would require placement of two microphones on the listener's head. The purpose of the present study was to determine the feasibility of using a two microphone configuration on a listener's head under realistic listening conditions; i.e., conditions which included head movement and in a reverberant environment.

Recordings for processing were made in the following manner. Two microphones were placed on the head of a listener in a reverberant room, (reverberation time = .39 sec). A directional microphone was used as the reference microphone and was placed facing the noise source. An omni-directional microphone worn at the listener's right ear served as the primary microphone. Monosyllabic words (NU Auditory Test No. 6) and speech spectrum-shaped noise were introduced into the room through two loudspeakers. The listener faced the loudspeaker through which the speech signal was transduced. The second loudspeaker was placed behind the listener. The listener was positioned midway between the two loudspeakers. The speech signal was set to deliver a signal of 72 dB SPL measured at a distance of one meter from the loudspeaker. The noise was set to result in a signal-to-noise ratio of 0 dB measured at the output of the primary microphone. The output of the two microphones was amplified and recorded onto a two-track recorder.

Two conditions of head movement were included as test conditions. In the "no movement" condition, the listener maintained her head position fixed during recording. In the "moderate movement" condition, the listener moved her head systematically from right to left by ± 13 degrees and up and down by ± 10 degrees.

The output of the tape recorder was processed through a Widrow filter. Processing was performed on a Modular Adaptive Signal Processor with a 12 bit A/D and D/A. The length of the adaptive filter was set to 800 taps and a 10,000 Hz sampling rate was used. A scaler setting of 1 and a delay setting of 0 were used in the reference channel.

Five normal hearing listeners, listened to recorded speech-in-noise under four listening conditions:

1. Unprocessed condition - no head movement; 2. Processed condition - head movement; 3. Unprocessed condition - moderate head movement; 4. Processed condition - moderate head movement

Mean scores for the four listening conditions appear in Table 2. The data were analyzed using a repeated measures analysis of variance to determine the effect of processing and of head movement. Processing was found to result in a significant increase in word recognition ($p<.05$). Head movement caused a decrease in the effectiveness of processing ($p<.01$), but still resulted in a substantial improvement in speech recognition score (29.2%).

DISCUSSION

The Wiener filter was found to increase recognition of speech in noise for several hearing-impaired listeners. However, the implementation of an adaptive Wiener filter in a wearable hearing aid would be impractical. A necessary stage of such an amplification system. Even if such a device were available, processing could not be achieved in real time.

The Widrow filter is by far the most promising of the techniques we have evaluated. The results obtained on five normal hearing subjects are encouraging. It remains to be seen whether similar improvements will be obtained by hearing-impaired listeners. Further studies to evaluate the effect of varying amounts of reverberation, background noise, and head movement are in progress.

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Table 1. Mean scores (percent correct) on the CUNY NST under two listening conditions.

Subject	Unfiltered Condition	Wiener Filter Condition
1	65	78
2	71	71
3	65	60
4	50	57
5	46	55
6	74	73

Table 2. Mean scores (percent correct) on the NU Auditory Test No. 6. under four listening conditions.

	Unprocessed Condition	Processed Condition
No Head Movement	34.0	73.6
Mod. Head Movement	33.2	62.4

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Functional Gain Measurements of Amplitude and Phase

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ABSTRACT

Measurements of the frequency-gain characteristics of hearing aids have focussed almost exclusively on the amplitude-frequency response. A method for measuring the phase-frequency response is described using an extension of the functional gain technique. A subjective cancellation procedure is used which allows for precise measurement of both amplitude and phase characteristics.

INTRODUCTION

The phase-frequency response of hearing aids has seldom been of interest in either the design or prescriptive fitting of these instruments. This is presumably because the phase characteristics of audio signals are generally regarded to be of little practical consequence. Whereas the ear is relatively insensitive to phase in monaural listening, it is remarkably sensitive to phase in binaural listening. A normal-hearing listener, for example, can detect an interaural phase difference of less than 5 degrees at 1000 Hz (1). This corresponds to an interaural time difference less than 15 microseconds, an extremely small difference by any standard for human signal processing.

Since the vast majority of hearing aids are designed for monaural use, it is not surprizing that the phase characteristics of hearing aids have received little attention. Even the so-called binaural hearing aid is typically no more than a pair of monaural hearing aids that have been fitted individually to each ear. The exquisite sensitivity of the binaural system to interaural phase differences is simply not being taken into account in either the design or fitting of binaural aids.

There are additional reasons for being concerned with the phase characteristics of hearing aids. Acoustic feedback can be reduced by manipulation of the phase characteristic of the hearing aid. It is also possible to reduce the peak factor of amplified speech signals by manipulation of the phase characteristic. Reducing the peak factor can be used to reduce the amount of distortion produced by peak clipping, a technique often used to protect hearing-aid users from occasional, intense sounds.

Whereas it is relatively difficult to control phase precisely in conventional analog circuits, it is no more difficult to control the phase-frequency response in a digital filter as the amplitude-frequency response. Since the next generation of hearing aids is likely to include some form of digital processing with greater control of the phase characteristic, it is important that methods be developed for measuring and calibrating the phase of hearing aids.

SUBJECTIVE CANCELLATION TECHNIQUE

A very sensitive method of measuring relative phase is by means of subjective cancellation. In this technique a test tone amplified by the hearing aid is cancelled by a reference tone at the same frequency reaching the cochlea by an alternative route. The alternative route could be by bone conduction or by means of the electrophonic effect (2). In order to achieve cancellation it is necessary to adjust the amplitude and phase of either the test or reference tone such that, on reaching the cochlea, they are equal in amplitude but opposite in phase.

The following example shows how the technique was used in measuring the relative phase of a digital hearing aid. The hearing aid consisted of a conventional hearing aid microphone followed by a 32-tap FIR digital filter, power amplifier, limiting network and output transducer. The hearing aid was first programmed to have a flat electrical response. This was the reference condition.

It was of interest to determine the phase-frequency response at the ear for a 90 degree phase shift in the digital filter. The transfer function from sound field to microphone was not of interest in this example and the test signal was applied electrically to the digital hearing aid. The reference signal was delivered by means of bone conduction. A low-distortion sine-wave generator was used as the signal source. The output of the signal generator was split into two parts, a test signal and a reference signal. The latter signal was first fed to a phase shifter, then amplified and applied to a conventional bone-conduction transducer mounted on the mastoid. The test signal was led directly to the electrical input of the digital hearing aid.

The hearing aid was adjusted to deliver a signal at a comfortable listening level. The test signal was then switched off and the reference signal switched on and adjusted in level to be slightly louder than the test signal. Since the reference signal was transmitted by bone-conduction it was received by both ears resulting in a binaural sound image located between the two ears. Masking noise was added to the non-test ear. As the level of the masking noise was increased the perceived position of the reference tone moved to the test ear. The masker level was increased until the reference tone reached the test ear and further increases in masking produced no further change in the perceived position of the reference tone.

Both the test and reference tones were switched on and the amplitude and phase of the reference tone were then adjusted until the two signals cancelled each other. An iterative method of adjustment was used. The amplitude of the reference tone was first adjusted such that, when heard alone it was roughly as loud as the test tone heard alone. The phase shifter was then adjusted until the combined tone reached a minimum in loudness. The amplitude of the reference tone was then adjusted to obtain a lower loudness minimum. The phase shifter was then adjusted to reach an even lower loudness minimum, and so on, until the combined tone was no longer audible. At this stage the test and reference tones had effectively cancelled each other.

The adjustment procedure was found to be both rapid and precise. Typically, only three or four adjustments were needed in order to achieve cancellation. The precision of adjustment was such that changes of several Hz in the test frequency would require a re-adjustment to achieve cancellation. For this reason the use of a frequency counter is recommended so as to set each test frequency with high precision.

At cancellation, the rms voltage and relative phase of the reference tone was recorded. The measurements thus obtained provided baseline data for the purpose of evaluating a programmed change in the phase characteristics of the digital hearing aid. The hearing aid was then re-programmed to have the same amplitude-frequency response but with a 90 degree phase shift at all frequencies. The cancellation procedure was then repeated. The difference between the two sets of measurements shows the change in gain, for both intensity and phase, resulting from the re-programming of the hearing aid.

The above measurements were repeated for each frequency of interest. The experiment was then repeated in order to obtain an estimate of test-retest variability.

The data are summarized in Table 1. The test-retest variability was found to be 1.4dB for the amplitude measurements and 8.5 degrees for the phase measurements. The digital hearing aid was programmed for a change in gain of 0dB and 90 degrees phase shift at all frequencies. The data, however, show systematic changes in both intensity and phase as a function of frequency. These differences were due to the limitations of the 32-tap FIR digital filter. Electrical measurements of the gain of the digital hearing-aid show changes in intensity and phase with frequency similar to those obtained for the subjective cancellation technique.

CONCLUSIONS

The technique described above is similar in concept to the method of functional gain (3) since the overall gain of the hearing aid, including all effects from hearing-aid input to the perception of sound reaching the cochlea are taken into account. The technique, however, differs from the functional gain approach in that a cancellation technique is used which not only increases the precision of measurement but also allows for the measurement of both amplitude and phase characteristics. The technique can also be extended to measure the detectability of harmonic distortion components produced by the hearing aid.

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Table 1. Measured Change in Functional Gain

		Frequency (Hz)				
		250	500	1000	2000	4000
Intensity	Replication 1	-2	0	-1	-2	5
Change	Replication 2	-2	-5	-1	1	3
(dB)	Mean	-2	-2.5	-1	-0.5	4
	Std Error	1.4				
Phase	Replication 1	61	91	85	115	89
Change	Replication 2	52	72	102	90	79
(degrees)	Mean	56.5	81.5	93.5	102.5	84
	Std Error	8.5				

HUMAN FACTORS CONSIDERATIONS IN THE DESIGN OF LARGE PRINT DISPLAYS FOR PERSONS WITH VISUAL IMPAIRMENTS

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ABSTRACT

The Atlanta Veterans Administration Medical Center Rehabilitation Research and Development Unit (VAMC Rehab R&D Unit) has been conducting research with the readability of computer displays by persons with visual impairments. The current study was a design project to develop a device to format Large Print Displays (LPDs) for use by persons with limited usable vision. Specifically, a video display interface which formats video data was designed, built and tested. It is intended that the user of this device be able to choose among several possible text and presentation formats, choosing the one which meets the person's particular need and application. A Large Print Display Reading Protocol was developed by the researchers. This test protocol entailed approximately two hours of assessment and evaluation that determined the comfort-based reading preferences for the low vision person viewing large prints on the display.

BACKGROUND

In 1983, Reader's Digest reported a circulation of 308,600 of their Large Type Edition, while the New York Times Large Type Weekly reported a circulation of 50,000 copies per week. Large print for the visually impaired reader has traditionally been produced by either printing press or microfilm duplication. The cost for large print production by microfilm enlargement, the less expensive of the two methods, can be as much as 30 to 40 cents per page. In addition, microfilm duplication does not lend itself to reformatting, nor does it compensate for variable print sizes. Although printing press production does allow reformatting, the high cost makes it impractical for almost any application besides those with mass circulation.

There are now several devices to aid visually impaired persons in reading, but most are directed toward those individuals so severely affected as to require braille [8]. One such device is the Optacon reading aid, which uses character recognition to "read" printed material and convert it into tactile output. There are also several computer peripheral devices which are designed for speech or braille output. The effectiveness of these output devices is severely reduced since there is little integration with commercially available software programs (e.g., word processors and data bases).

Of the very few low vision reading aids on the market today, the most well known and used is the Closed Circuit Television (CCTV). The CCTV provides greater magnification without such problems as short focal length and critical focusing distance, but it is expensive and not very portable. It also requires careful manual adjustment and alignment severely limiting its use for many visually impaired persons.

While the world of business and many private individuals have been utilizing the microcomputer in rapidly expanding numbers for a variety of professional and personal reasons, the visually impaired user has been left with limited and expensive means to access computerized information. Access to computers would be simpler for these persons if a suitable video display providing large print were available.
It is estimated that 70% of the visually impaired population have sufficient residual vision to utilize large print [3].

The use of microcomputers to produce large print on video monitors has been limited because of numerous design limitations [5]. Many of these limitations are human factors considerations which are largely ignored in the design of current LPDs. These can be broken down into three categories: the large print itself, the amount of information which is displayed, and the control of the display. Insufficient attention to these categories has resulted in displays which can be confusing and difficult to use.

The difficulty of incorporating good human factors design into computer display design is that there has been little formal research into the various large print and display parameters of LPDs.

The research on computer displays has typically been conducted with normally sighted individuals, lending the results inappropriate for the design of LPDs for visually impaired persons. For example, the results of the research on dot-matrix print sizes by Pastoor et al. [6] are not applicable to persons with less than 20/20 vision, while the results of the comparison of windowing versus scrolling [2,7] do not take into account the special problems involved in trying to read oversized print from a standard sized screen. Compounding the problem of applying research from normally sighted individuals to the visually impaired is the finding that optimal print style is dependent on the kind of residual vision and on individual differences [4].

In the current study, attempts were made to develop a set of LPD design criteria for computer displays and to determine the relationships between these criteria and the reading behaviors of the visually impaired subjects. In order to achieve this goal, a systematic approach for testing and evaluating the human factors design parameters for LPDs was required. The Rehab R&D unit has developed a Large Print Testing Protocol to facilitate standardization and ease of collecting data with the visually impaired population.

METHODS

Low vision students (n=16) were recruited from local high schools. Students were chosen for the study because they are active and practiced readers and typically exhibit good motivation toward such studies.

A Voyager XL Visualtek closed circuit television system (CCTV) was used to obtain initial assessment of font syle and size preference. Samples of 11 fonts were presented for inspection on the CCTV. A sample of these font styles is provided in Figure 1.

The LPDs were generated on two different computer systems: (a) a Hewlett-Packard Model 9000, Series 300 (MC68010 based computer with bit mapped color graphics) and (b) an Apple IIe with an 80 column card and 64K RAM. The Hewlett-Packard system permitted high resolution font generation, efficient manipulation of character and line spacing, and extensive control of letter and background color. The Apple IIe provided an LPD (with some constraints to character size) and, additionally, offered text scrolling capability. The display for the Apple IIe was a standard green monitor. Character spacing was controllable to within one pixel. The Apple IIe permited 280 pixels horizontal resolution and 192 pixels of vertical resolution. (The Apple IIe was chosen primarily because it is a low cost and widely used system.)

Several parameters of LPD were investigated with the CCTV: a) font style, b) character size or magnification, and c) reversed background/ foreground. Additional parameters were available for study on the Hewlett Packard computer: a) character spacing, b) word spacing, c) line spacing, and d) color contrast.

A measurement of sustained readability of the LPD which incorporated the subject's preference of font, size, and spacing required a test of the subject's reading comprehension and speed with the preferred LPD. Hence, a measurement of the readers' display preferences was compared with their actual reading skills.

Since a "standardized reading comprehension test" for low vision persons was not found in the literature, the investigators developed one which was incorporated in the current study. The "Timed Readings Test" [9] was adapted for experimental use because of its short passages, large range of reading levels (6th grade to college), and wide acceptance in the school systems.

Each subject reported to the laboratory for a three hour session. During this session, a brief questionnaire was administered to obtain information concerning visual impairment and current reading behaviors. The set of 11 fonts was then presented via the CCTV for ratings of readability, desired magnification, and general preference.

Each subject read passages containing 400 words of factual information. The criterion for reading level was a comprehension of 70%. The comprehension test was composed of ten questions. There were five thought (inferential comprehension) and five fact questions (literal comprehension). Reading speed was recorded for the subject's criterion reading level. Passages printed in both a standard font (TMS Roman) and the subject's preferred font was presented on the CCTV.

A font incorporating the subject's style and size preferences was then generated on the Hewlett-Packard system. A 4 point rating scale ("very readable"....."not readable") was used to investigate the readability of the other computer generated LPD parameters.

The subject was then introduced to the Apple IIe which was capable of reproducing the subject's preferred LPD font styles and sizes on the screen. The text appeared as a single line in the middle of the monitor screen. The scroll rate of the text could be changed by the subject using keyboard input to cursor keys. The text could be stopped, slowed, or reversed by the subject as desired.

New passages of the reading comprehension test, displayed in both the standard (TMS Roman) and the preferred font, were presented to the visually impaired person. Again the subject's reading speed was recorded for the criterion reading level.

RESULTS AND DISCUSSION

The subjects' reading performance on the CCTV was compared to their performance on the Apple IIe.

Research is ongoing at the present time, therefore, the results will be delivered at the RESNA conference.

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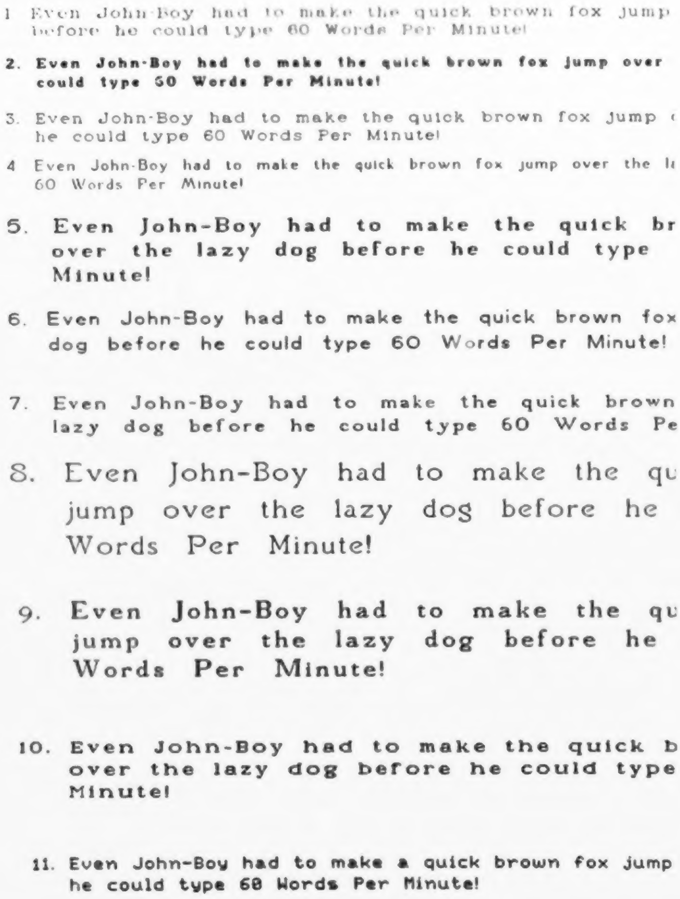

1 Even John-Boy had to make the quick brown fox jump
before he could type 60 Words Per Minute!

2. Even John-Boy had to make the quick brown fox jump over
could type 60 Words Per Minute!

3. Even John-Boy had to make the quick brown fox jump
he could type 60 Words Per Minute!

4 Even John-Boy had to make the quick brown fox jump over the
60 Words Per Minute!

5. Even John-Boy had to make the quick br
over the lazy dog before he could type
Minute!

6. Even John-Boy had to make the quick brown fox
dog before he could type 60 Words Per Minute!

7. Even John-Boy had to make the quick brown
lazy dog before he could type 60 Words Pe

8. Even John-Boy had to make the qu
jump over the lazy dog before he
Words Per Minute!

9. Even John-Boy had to make the qu
jump over the lazy dog before he
Words Per Minute!

10. Even John-Boy had to make the quick b
over the lazy dog before he could type
Minute!

11. Even John-Boy had to make a quick brown fox jump
he could type 60 Words Per Minute!

Figure 1. Sample of the 11 fonts used to determine the subject's "preferred font".

TIME AND TIME AGAIN, SAY IT WITHOUT FEELING:
TWO NEW DEVICES FOR DEAF-BLIND PEOPLE

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ABSTRACT

With the two primary input channels of vision and hearing inoperative, an enormous range of information which is part of everyday life of the general public is unavailable to deaf-blind people. Sensory aids which present this information tactilely and/or kinesthetically help fill the void for this population. This paper will present two new sensory aids for the deaf-blind, one addressing the simple need to know when to do something, and the other aimed at solving the problem of receiving both written information and remote interpersonal communication.

INTRODUCTION

The answers to the "who, what, why, how" and "when" questions form the substance of most people's interactions with the world and with other people. The majority of this information is received through the visual and auditory channels. When these channels are not usable, as is true for deaf-blind people who have no functional hearing or vision, the tactile channel becomes of immense importance as a substitute.

While visual and auditory information can often be efficiently swapped for each other (e.g., it makes little difference whether one reads a voltage by seeing where the needle is on the scale, or hears it stated via synthetic speech), the tactile channel is almost always a poor substitute for all but the most simple visual or auditory information. The tactile channel takes more time to receive the information and has limited capacity to handle the type of complex information associated with the two primary remote sensors. In addition, from an engineering point of view, it is difficult to design and fabricate devices which can provide tactile outputs which are an efficient information transfer system, as well as simple to use, cosmetically acceptable, affordable, etc. For example, highly motivated consumers who are willing to cope with the reality of trade-offs have greatly benefited from the use of braille and/or tactile Morse Code, but both systems require the user to learn an atypical communication system. In addition, each has its inherent drawbacks such as the bulk of hard-copy braille, the expense of volatile braille devices, the constant tactile impact required for receiving the Morse Code, etc.

As if developing tactile-output devices weren't challenging enough, the device development team may find itself faced with the need to devise a sensory aid for a deaf-blind individual who has lost his functional sense of touch (as is seen in peripheral neuropathy associated with diabetic retinopathy) or who has lost the ability to employ the sense of touch (as seen in carpal tunnel syndrome which may be related to years of using the hand for communication). With no means of receiving spoken or written information via vision, hearing, or touch, these individuals experience an intolerable degree of isolation.

Two projects are under way at the Smith-Kettlewell Rehabilitation Engineering Center which address these problems.

The first addresses how to enable deaf-blind people to know "when;" the second addresses how to enable deaf-blind people who have lost the ability to utilize tactile information to know "who, what, why" and "how," that is to say, to receive communication in general.

TIME AND TIME AGAIN:
PROGRAMMABLE VIBRATING REMINDER

The passage of time and specific time-related events are perceived effortlessly throughout the course of the day by observing changes in both natural and artificial lighting, the activities of other people, odors in the environment, etc. While smelling food cooking might alert the deaf-blind individual to the fact that it is almost lunch time, the majority of environmental changes which are signalled visually or auditorally are not available. Use of a braille watch can inform the user of the time at the moment he reads it, but it does not solve the need to know when it is the correct time to do something. The result of this problem may be inconsequential, such as a missed meal; major, such as a missed important class or meeting; or catastrophic, such as missed medication.

To address this problem, the Smith-Kettlewell Rehabilitation Engineering Center commissioned the fabrication of a prototype Programmable Vibrating Reminder (Figure 1) for use by deaf-blind persons.* It consists of two parts: (1) a programming unit approximately 9 inches wide by 8 inches deep by 3 inches high, and (2) a pocket-sized vibrating unit. The programming unit comprises various buttons, knobs, and switches to enable the user to "tell" it up to 10 different signal times desired in any 24-hour period. It also has a liquid crystal display for the sighted user to confirm signal times, and a single vibrating pin for the blind user to confirm signal times. Of course, the visual display allows the viewer to read hours, minutes, and seconds at a single glance. The tactile presentation is much more painstaking to read as it requires the user to count the number of pulses at different vibratory frequencies to determine the different aspects of each alarm:

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* Mr. Herb Cohen, designer of the Tactile Communicator for the deaf-blind developed at the Helen Keller National Center, designed and fabricated the Programmable Vibrating Reminder.

435

first the user feels the presence or absence of a .5 second 128 Hz signal to determine whether or not the setting is AM or PM; next the user must count the number of 64 Hz pulses of .25 sec duration to know the hour setting (if this involves two digits, this procedure is repeated for the second digit); finally the user must count the number of 32 Hz pulses of .25 duration to know the minutes' setting (again, if this involves two digits, this procedure is repeated for the second digit). Values of zero are signified by an 8 Hz pulse of .5 sec duration.

Despite the comparative ease of reading the visual display relative to the tactile display, the procedure of setting the various alarms is one which is more complicated than it is intuitive for both the LCD and the vibrating pin user. Once either the sighted or deaf-blind operator has patiently invested the time to learn the procedure he is rewarded with being able to conduct this operation rather mechanically. The rigor required to arrive at that point, however, appears to be beyond what most consumers are willing to pursue. This is especially true for the vibrating pin user who must function with even more setting rules than the visual display user. For example, the vibrotactile output is not operative during the setting operation, so the deaf-blind user cannot monitor the validity of his setting procedure as he works through it.

The motor aspects of operating the Programmable Vibrating Reminder are also demanding. To set Hour, Minute, and Second, the H, M, or S button must be depressed at the same time that the appropriate digits are depressed. Even more motor demands are placed on the deaf-blind user needing to read the setting times. This requires depressing the number of the setting of interest (zero through 9) with a finger of the left hand, depressing the vibrotactile pushbutton with the right ring finger, feeling for the vibrotactile pin with the right index finger, and then releasing the number key which was depressed by the left hand!

Some simple design modifications could greatly enhance the ease of use of this device. For example, automatic activation of the vibrotactile pin during the read mode would totally eliminate the need for the vibrotactile pushbutton; toggle switching of or toggle switch replacements for the H, M, and S buttons would eliminate the need to hold them down in addition to the number keys in order to set reminder times.

As is always the case, however, much redesign to simplify would be made at the expense of size of cost. The single vibrotactile pin requires the user to count sequences of pulses, to keep track of what he is counting at that moment (i.e. AM or PM, hours tens or hours units, seconds tens or seconds units, or a zero value), as well as to retain this information in order to get the entire answer at the end of the operation! A linear array of vibrotactile pins would greatly decrease the complexity of the procedure as well as the memory demands, but would add to the size and cost of the unit.

The solution may very well lie in a tremendous simplification of the overall goal as well as in greatly reducing the sophistication of the device. While 10 different reminder settings for a 24-hour period does not seem unduly excessive (e.g. 3 meals, 4 scheduled medications, and 3 meetings or classes), it may be more than necessary for the typical deaf-blind consumer who "lives life in the slow lane." In addition, sometimes what appears to be more involved at first blush may actually be a powerful simplifier over all. Ms. Geraldine Lawhorn, an instructor at the Hadley School for the Blind, recently wrote to one of her students about the need for deaf-blind people to utilize timers. She herself uses the simple mechanical wind-up unit which sighted people use to remind themselves to add money to their parking meter. Although intended as auditory output devices, these have enough vibration to be detected tactilely by some deaf-blind consumers. It would probably be less expensive to modify these to have longer and stronger vibrations for those who need it than to develop a sophisticated programmable unit. Of course, resetting would have to be done frequently throughout the day, but that would be such a simple procedure as to make it almost trivial. Or, one could use two or three different timers, possibly with different total and interval time settings.

SAY IT WITHOUT FEELING: DOTLESS BRAILLE READER

Diminished tactile sensitivity is sometimes associated with deaf-blindness, either from a common disease etiology or from over-use of the hands as an information channel. For deaf-blind individuals who formerly relied on braille for written information as well as remote interpersonal communication (i.e. via the telebraille), diminished tactile sensitivity exacerbates an already painfully isolating condition. The Smith-Kettlewell Rehabilitation Engineering Center is fabricating a braille reading machine which uses the kinesthetic rather than the tactile sense. It looks much like an electronic braille keyboard, but rather than being used to "write" by pressing the keys down, these keys are computer-driven to move up under the user's fingers.* The letter-by-letter input from the computer determines which groups of keys move up at any time, in accordance with the braille code. Thus, what looks like a keyboard is really the equivalent of a refreshable braille display with each of the six dots replaced by a key and relocated to fit under each of six fingers.

A pre-prototype dotless braille consisting of only two keys (Figure 2) has been fabricated to allow us to conduct a human factors study vital to the design of the prototype keyboard. The question simply was which is preferred--having the keys fall away from under the user's fingers, or having them push up against them? The consensus of blind and sighted braille and non-braille users was to have the keys move upward. In addition to being the preferred choice for ease of perception, the upward movement has the added advantage of reducing possible confusion between the read and write modes. That is, for sending information via the braille code, the user presses keys down; for receiving information via the braille code, the user will detect the keys moving upward. This will become more important if the dotless braille reader eventually also becomes an electronic braille writing device, either with a separate writing keyboard or with the ability to use the same keyboard for both reading and writing.

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* The author wishes to thank David Boonzaier, M.D., University of Capetown, for assistance in the development of this concept.

The Smith-Kettlewell Rehabilitation Engineering Center has just learned that a commercial product of the Central Association of the Visually Handicapped in Finland, DiaLogos, incorporates our basic concept of replacing the typical six-braille-dots arrangement designed to be detected by a single finger, with six information points arranged to be detected by six different fingers. It was interesting to learn that these dot indicators move up against the user's fingers as is intended for our future prototype. However, our major concept of using the intact kinesthetic sense rather than the dysfunctional tactile sense is not incorporated in the Finnish device. Their DiaLogos utilizes 6 pins about 2mm in diameter to impinge upon the finger pads, in sharp contrast to the keys of the Dotless Braille Reader which will push the entire finger upward. We have initiated steps to allow for a comparison of these two different approaches once our prototype is completed.

CONCLUSION

Sensory aids and tactile or kinesthetic outputs are capable of providing deaf-blind people with important information. Designing such devices is especially difficult because of the inherent restrictions of these sensory channels, as well as because of the problems associated with the mechanical nature of the devices which can provide these types of signals needed for tactile or kinesthetic perception. Careful consideration of the needs of the deaf-blind community as well as of the requirements for a system which must be utilized without assistance from either visual or auditory information can result in the development of sensory aids of vital importance in reducing the isolation experienced by deaf-blind people.

Acknowledgments
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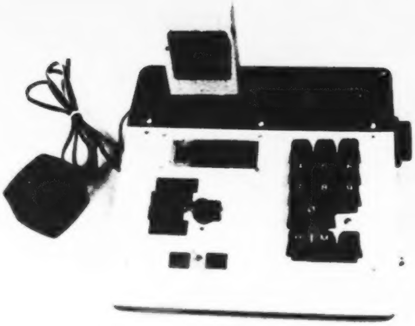

Figure 1. Prototype Programmable Vibrating Reminder

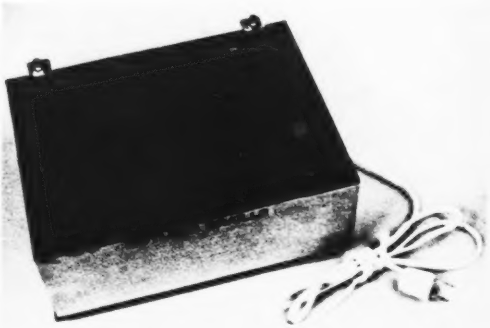

Figure 2. Pre-prototype Dotless Braille Reader

PORTAPITCH II: A MULTICHANNEL TACTILE DISPLAY OF VOICE FUNDAMENTAL FREQUENCY

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ABSTRACT

Improvements have been made to a wearable, tactile display that encodes fundamental frequency (F0) as locus of pitch-synchronous vibrotactile stimulation. Using a desk version of this device, word recognition in sentences was measured in normal subjects by lipreading with and without tactile supplementation. Performance was also measured with a single channel display that presents F0/2 to the finger. Lipreading scores increased slightly with supplementation, but the single and multichannel systems did not give different results. Much larger improvements, using the multichannel system, were found after 10 hours of practice during a follow-up study using a hearing-impaired subject.

INTRODUCTION AND PURPOSE

Lipreading performance in normal adults rises dramatically when the visible movements of speech are supplemented by fundamental voice frequency (F0), presented auditorily. It might be predicted, therefore, that a device that provides an unambiguous tactile representation of F0 would serve as a significant aid to lipreading in the postlingually deaf. Such a device has been developed by Boothroyd <1>. It encodes F0 as both the frequency and the locus of vibrotactile stimulation of the skin. The present version, which we call Portapitch II, represents a significant improvement over the prototype. The pitch period meter employs a microprocessor, thus permitting the implementation of correction and smoothing algorithms. Moreover, the number of output channels is easily adjusted from 1 to 16. The pitch extraction circuits have been improved for more reliable function over a wide range of talker F0 values and talker-microphone distances. The output transducers have been quieted, and battery life between charges has been increased to 6 hours. Other human engineering improvements have rendered the device more acceptable to potential users.

Of primary concern, however, is the effectiveness of the device. Preliminary data indicated that it was effective in providing access to those speech pattern contrasts that are cued by F0 patterns and by duration <2>. In a preliminary study, significant improvements in sentence perception were observed, after only brief training, when the device was used as a supplement to lipreading <3>. Similar improvements, however, were observed with a single channel display in which the frequency of vibration was F0/2. The data to be reported here are from continuing performance evaluation. The purpose was to measure sentence perception during training with and without tactile supplementation of lipreading.

SUBJECTS

Six normally hearing adults participated in this experiment. White noise masking was used to prevent them from hearing the acoustic output of the transducers.

TACTILE STIMULATION

Two tactile systems were used: a) a 16 channel, desk version of Portapitch, the transducer array being placed on the left forearm; b) a single channel device that stimulated the left index finger at F0/2, using the same type of solenoid as that used in the multichannel device. Input to the pitch extractor was by direct connection, using a signal derived from an electroglottograph.

TEST/TRAINING MATERIALS

Word recognition in sentences was measured using the CUNY topic-related sentence sets <4>. There are 48 sets of 12 sentences each. Within a set, length varies from 3 thru' 14 words and each sentence is about one of a set of 12 topics: food, family, pets, etc. A single score is based on 102 words and is the percentage of words recognized, regardless of type or function. All materials were video-taped by a female talker and were presented via a computer-interactive system, using a semi-automated version of the discourse tracking procedure of DeFillipo and Scott <5>. All scores are reported for the first presentation of a sentence and are the average of 4 sentence sets (i.e., 408 words).

PROCEDURE

Each subject received 1 hour of training by lipreading alone, 2 hours by lipreading with one tactile supplement, a half hour probe by lipreading alone, 2 hours by the other tactile supplement, and a final half hour lipreading-alone probe. Sessions were spread over several days in half hour blocks. The order of exposure to the two tactile supplements was counterbalanced among subjects.

RESULTS

Performance, as a function of training session, is shown in Figure 1. Scores improved over time for all conditions, but supplemented conditions remained better than lipreading alone. The differences were small, however, amounting to only a few %pts. When the data were examined in relation to the type of tactile supplement, it was not possible to show a superiority for the multichannel over the single channel.

FOLLOW-UP STUDY

We hypothesised that the experience provided to these subjects was simply too limited to permit the kind of learning required for integration of visible and tactile/spatial patterns in speech perception. To test this hypothesis, we carried out a follow-up study. A single hearing-impaired subject received 2 hours per week of training in speech perception, using the semi-automated tracking procedure. Three, 1 week blocks of training with the tactile supplement were interspersed with single 1 week blocks of training by lipreading alone. The results are shown in Figure 2. Lipreading-alone scores remained fairly constant (and high) at around 67%. The supplemented scores rose, however, reaching around 84% after about 14 hours. Although the difference in absolute terms is only 17%pts., this improvement represents a 50% reduction of error. These results are much more encouraging. They also serve to emphasize the need for large amounts of training in the interpretation of markedly novel sensory codes. It remains to be seen whether single channel stimulation can be as effective after prolonged training.

DISCUSSION

The initial results were disappointing in two ways. First, they did not show the kind of dramatic improvement with the addition of F0 that occurs with the auditory modality. In fact, the changes were of the same order of magnitude as that found when lipreading is supplemented auditorily by a single frequency that conveys only the presence or absence of voicing <6>. The second disappointment was the failure to show a superiority for the multichannel spatial display. Both findings indicated that the subjects were not integrating intonation patterns with visible information, even though more analytic

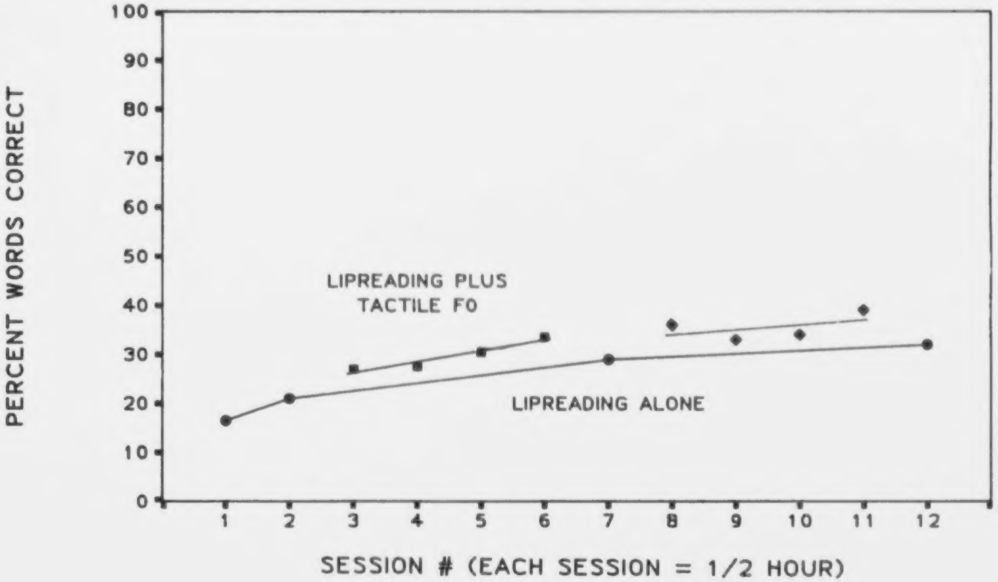

Figure 1. Percent correct words recognized in sentences, by lipreading with and without supplementation by tactile F0, as a function of training session. Data points are the average of 6 normal subjects.

studies have shown that the spatial display conveys information about those patterns. The follow-up study indicates that such integration can occur but that it probably requires much more training. Note also that the single subject used in the follow-up was an experienced and competent lipreader. It is quite possible that a minimal level of competence is required before novel sensory codes can provide an effective supplement.

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Portapitch is protected by US patent # 4581491, 1986.

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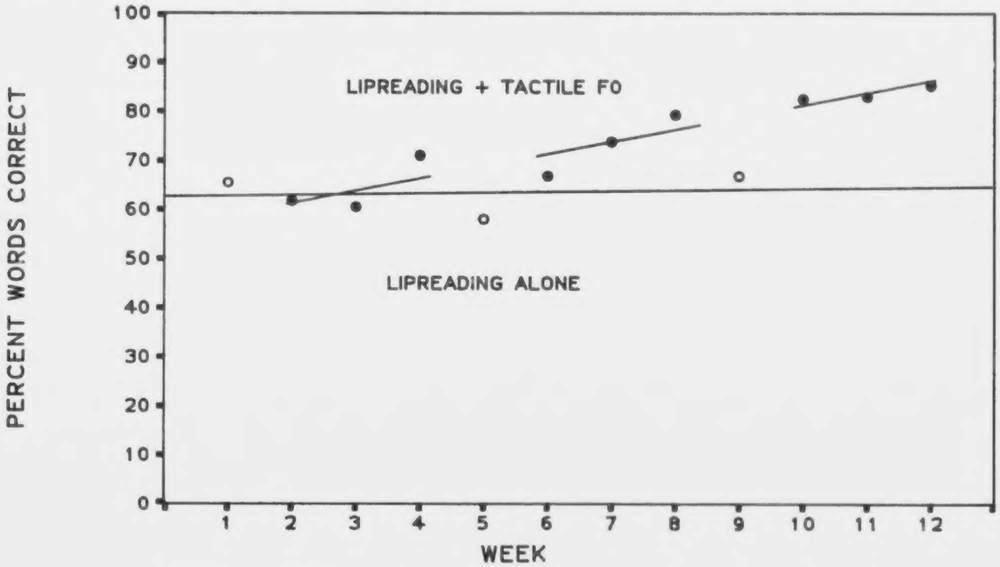

Figure 2. Percent correct words recognized in sentences, by lipreading alone and lipreading supplemented with tactile, spatial F0, as a function of weeks of training. These data are for a single hearing-impaired subject.

DEVELOPMENT OF SPEECH PERCEPTION SKILLS IN COCHLEAR IMPLANTEES

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ABSTRACT

Recipients of cochlear implants must learn to interpret a novel sensory code. This study was designed to compare no-treatment, phonetic-level training, and sentence-level training, in terms of the rate of acquisition of phonetic and sentence perception skills. Five subjects were studied for 1 month before, and 6 months after, fitting with the Nucleus 22 channel implant. For sentence perception by implant-plus-lipreading, the biggest improvements were after initial receipt of the implant and during the month adjustment period immediately following. To the extent that training was effective after this time, the changes were small, and they tended to occur during sentence training rather than phonetic training. Marked inter-subject differences preclude generalization to all implants and implantees.

INTRODUCTION AND PURPOSE

Cochlear implants provide a sensation of hearing through electrical stimulation of the auditory nerve. They are designed to restore a sense of hearing to individuals who are totally deaf because of a non-functioning cochlea. An external processor transforms the acoustic signal into time-varying patterns of electrical potential at one or more electrodes (at the time of writing, the maximum number is 22). The patterns vary in complexity. Some systems replicate only the temporal characteristics of the acoustic waveform. Others produce a spatial representation of the spectrum. Still others extract salient features from the acoustical patterns and encode them in temporal or spatial dimensions of the patterns of electrical stimulation <1,2>.

The patterns of neural activity generated in the auditory nerve by an implant are different from those generated by the normal organ of corti. The implantee must, therefore, learn to interpret a novel sensory code. The work to be described was intended to answer two questions: 1) is this learning facilitated by the addition of structured training to the demands of daily communication? 2) If training is beneficial, does it make a difference whether it focuses on the perception of phonetic detail or on the perception of sentences?

IMPLANTEES

We will report data for 5 adults who were recipients of the Nucleus cochlear implant. This is a 22 channel system that encodes fundamental voice frequency as frequency of pulsatile electrical stimulation, and the frequencies and amplitudes of the first and second vocal tract formants as locus and intensity of that stimulation. Prior to implantation, all five were determined to be totally deaf. The ages at which they became deaf ranged from 5 years to 60 years. The time between acquisition of total deafness and receipt of the implant ranged from 6 months to 20 years.

TRAINING

Two types of training were used:

i) **Analytic**: Subjects were trained in the perception of stress and intonation contrasts, vowel contrasts, and consonant contrasts.

ii) **Global**: Global training was a semi-automated adaptation of the connected discourse tracking procedure of DeFillipo and Scott <3>.

The materials used for analytic and global training were video recorded by a female talker. They were presented via a computer-controlled, interactive video-tape system <4>. Equal amounts of training were provided via implant alone, lipreading alone, and implant-plus-lipreading.

TESTING

Progress was monitored with two speech perception tests:

i) **Speech Pattern Contrast (SPAC) test**: This test measures a subject's ability to perceive phonologically significant contrasts when they are presented in a varying phonetic context<5>.

iii) **Topic-related sentence test**: Percent correct recognition of words in sentences of known topic was measured using sets of everyday sentences developed for this work <6>.

The test materials were video recorded by the same talker used for the training materials and were administered with the same interactive system via all three modalities.

PROCEDURE

Each implantee was tested at the beginning and end of 7 periods, each lasting approximately one month:

i) **Pre-implant training**: Both analytic and global training were provided via lipreading alone and lipreading supplemented by high power amplification.

ii) **Surgery, recovery, and stimulation**: This period ended after the initial mapping of processed speech onto the subject's electrode array.

iii) **Patient and processor adjustment**: During this period, the patient followed the evaluation protocol outlined by the implant manufacturer. This included approximately 2 hours of live voice connected discourse tracking. Its purpose was to document performance and to permit further adjustments to the speech processor.

iv) **Treatment #1**: For approximately 4 hours per week, odd-numbered patient received analytic training and even-numbered patients received global training.

v) **No-treatment #1**: Patients received no formal training.
vi) **Treatment #2**: Odd-numbered patients received global training and even-numbered, analytic.
vii) **No-treatment #2**: Patients received no formal training.

RESULTS

Figure 1 shows the group mean sentence scores, as a function of test session, for the three modalities. The greatest single improvement in the score for implant-plus-lipreading occurred immediately after surgery and stimulation. The second greatest change occurred during the one month of patient and processor adjustment. After this time, small positive changes occurred during treatment sessions and small negative changes occurred during no-treatment sessions.

Figure 2 shows equivalent data for the average SPAC score. In this case, improvement occurred fairly steadily throughout the six months following acquisistion of the implant. Note, however, the marked increase in the implant-alone score immediately following surgery and stimulation.

The data were examined in terms of the changes occurring during analytic training, global training, and no-treatment. It was found that increases of score occurred more commonly during treatment than during no treatment, and that global training produced more increases than did analytic training. Moreover, the greatest increases were in the sentence scores, not the SPAC scores. It must be emphasized, however, that the sentence score changes were small compared with those occurring as a result of implantation and the month of adjustment immediately following surgery and stimulation.

The results just reported are for group data. Individual subjects differed markedly in the benefit they obtained from the implant, and the rate at which they acquired new speech perception skills.

DISCUSSION AND CONCLUSIONS

The following conclusions may be drawn from these data:

1. The most significant factor affecting sentence scores, for the lipreading-plus-implant condition, was the acquisition of the implant.
2. The second most significant factor was the patient and processor adjustment that took place in the month following surgery and stimulation.
3. Any subsequent changes were small.
4. When such changes occurred, they tended to be in response to global (i.e., sentence)

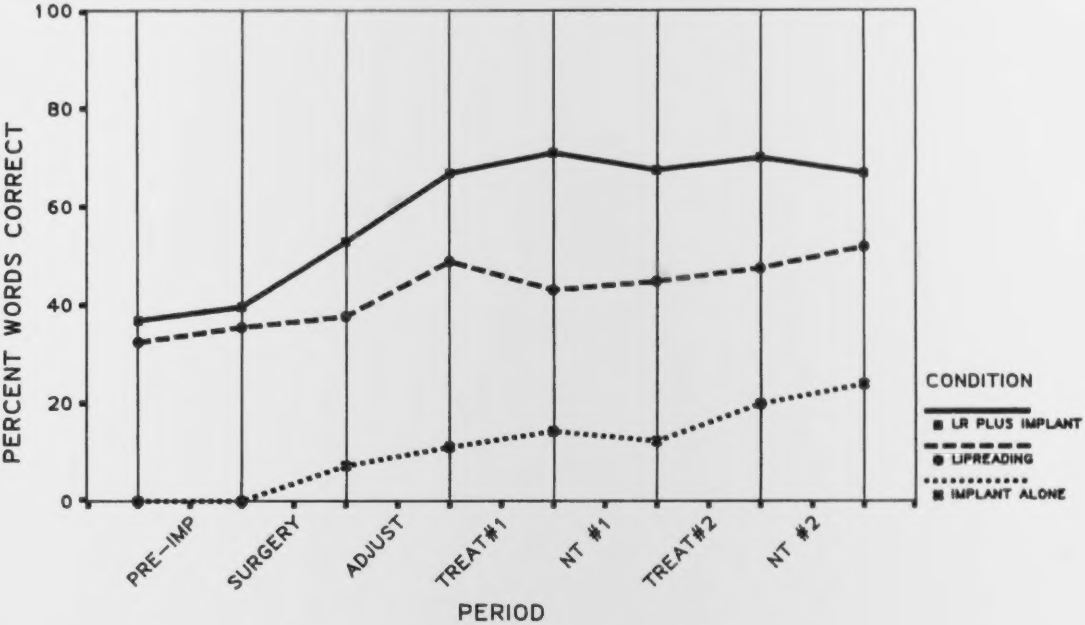

FIGURE 1: MEAN SENTENCE SCORES FOR 5 IMPLANT PATIENTS

training and to be observed mostly in sentence perception tasks.

Any attempt to generalize these data should be tempered by the following considerations:

1. The population of potential implantees is extremely heterogeneous. In particular, these data provide no guidance on the appropriate management of prelingually deafened subjects.
2. The amount of time spent on-task in any of the training procedures was small compared with the time spent in everyday communication.
3. The training procedures used here were not necessarily optimal.
4. These conclusions apply to the implant-plus-lipreading condition only. Performance with the implant alone did continue to improve beyond the adjustment period, and those improvements appeared to be influenced by training.
5. These results were obtained with a specific implant system.

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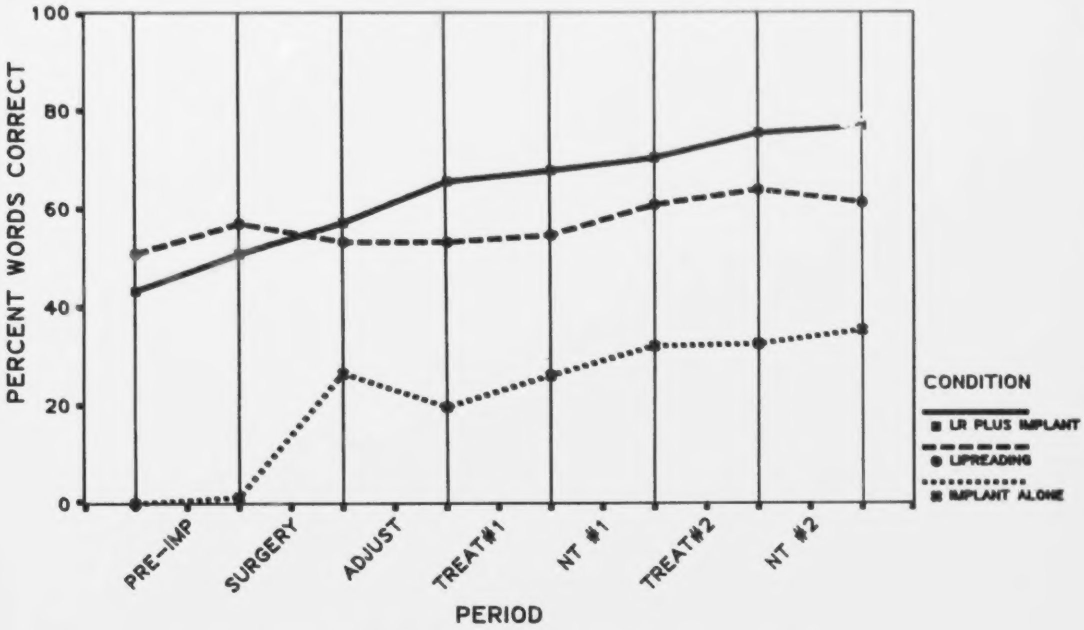

FIGURE 2: MEAN COMPOSITE SPAC SCORES FOR 5 IMPLANT PATIENTS
(SCORES CORRECTED FOR GUESSING)

DEVELOPMENT OF A PORTABLE TEXT COMMUNICATION ENVIRONMENT FOR THE VISUALLY IMPAIRED COMMUNITY

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Western Blind Rehabilitation Center
Palo Alto VA Medical Center

ABSTRACT

The PortaReader, a portable reading aid with text editing and review facilities, is being developed at the VA Rehabilitation R&D Center in Palo Alto, CA, to help meet the comprehensive reading and communication needs of the visually impaired community. The PortaReader will utilize commercially available components wherever possible to provide a cost effective solution for functional requirements. These components will be augmented by custom devices developed at the center to adapt them to the special needs of the user population and to integrate them into a unified system. The current paper describes two areas of on going work: 1) the process of determining useful operational features from two levels of user surveys and by simulation studies; and 2) the efforts to incorporate the results into an operational prototype system.

INTRODUCTION

Within the last ten year several technologically advanced commercial reading aids have been marketed. These existing reading aids have not been generally successful due to their high cost, restricted functionally, or lack of portability. The need for such a device is apparent considering that there are approximately 500,000 *totally blind* individuals in the United States, of which an estimated 50,000 are veterans. In addition, around 1.5 million Americans of impaired vision are classified as *legally blind*, including perhaps 200,000 veterans.[2]

BACKGROUND

In the past considerable efforts have been expended for development of reading aids for the blind. One device, the Kurzweil Reading Machine, (developed in the late 70's) is still by far the best commercially available automatic scanning OCR reading aid for the blind.[1] However, it is based on relatively old computer technology which forces the KRM to be immovable and quite costly ($19,000). Another device that had hand scanning capabilities, the HS-1, was developed and evaluated by Telesensory Systems, Inc., and found to be too difficult to operate by the target populations.[6] More recently, a commercially available OCR unit from Oberon has been investigated as a possible candidate as a reading aid. The Oberon Omni-Reader, incorporates several attractive features, such as small size, low price, and the ability to be interfaced to a personal computer.[7,8] This device, however, is quite restricted in its capabilities. Since all of these devices appear to be unable to meet the needs of a sufficiently large segment of the user group, further investigations into alternate solutions that incorporate the latest in computer technology were required.[12]

ANALYSIS OF/AND RESPONSE TO PREVIOUS WORK

Probably the most important lessons that can be learned from the less than total success of some attempts at building a reading aid are: 1) the device's performance and functional features must encompass a sufficiently large number of the users actual needs, so as to be accepted as a useful solution that will be utilized on a daily basis, and 2) it is paramount to provide a device that is consistant with the capabilities of the user group. The RR&D Center's response to these items was a logical and focused effort toward uncovering the pertinent underlying issues involved before embarking on, what could otherwise be, a potentially fruitless development project. To directly address the previous issues, the center proceeded by:

1. Multi-level in-depth user needs assessment surveys of the visually impaired community. These questionnaires were designed and given by the Western Blind Rehabilitation Center at the V A Medical Center in Palo Alto, CA, and the RR&D Center. The first questionnaire surveyed as wide as possible spectrum of the target population and covered many pertinent design topics; such as, potential types of usage for a text communication machine, types of reading materials considered important, and design characteristics.[5] A follow-up questionnaire resurveyed subjects that were identified as technologically expert users since it was felt that these individuals were the most technically competent and knowledgeable with regard to computerized communication aids.[3] The contents of the expert user survey focused on very detailed and extensive questions about past experiences with advanced aids and potential future communication aid features.
2. Simulation studies on potential reading aid features that are demanding of user performance abilities and other features that require careful human factors evalulations. Considerable effort was expended on simulation studies of audio and tactile feedback strategies for tracking of a hand held camera for an OCR reading aid.[4,9]

Furthermore, a survey of currently available commercial Optical Character Recognition (OCR) devices was conducted. It was determined that none of the devices met all of the requirements identified as important by the user surveys. however, technology was identified that could be packaged in such a fashion that could meet the goals.

DESIGN RESULTS: SPECIFICATIONS FOR AN IDEALIZED COMMUNICATION AID

Features of an idealized communication aid, with an integrated software and hardware environment, are being identified. Further refinement of these features are being done both by simulation on an enhanced Macintosh computer system and emulation of actual hardware and software on a IBM XT based development system at the RR&D Center. From this work, lists of features, performance parameters, and design constraints have evolved (and are still continuing to evolve).

The global level design consideration for the aid is that every individual has unique requirements and therefore the device must be adaptable to these varying needs. By being able to adapt the device, each user can configure a system that is resonably close to optimal with regard to their requirements and constraints. Furthermore, people's needs change as time passes, and a device that does not adapt could prove to be useless to them. At the time of the writing of this paper, the following reading and communication aid specifications appear to provide a useful solution to the daily reading needs of a sizeable group of the target population:

1. Computerized character recognition reader (OCR) with the following capabilities: maximum scan length of 14 inches, top scan speed of one line per second, multi-font proportionally spaced character recognition, and the ability to learn new fonts.
2. Option for handscanning the OCR camera for immediate access to text, with an audio tracking aid utilizing tones to

give to the user the necessary feedback to keep the camera over the text that is being inputted for computerized character recognition.

3. Synthetic speech output along with hand scanning, with continuous speech at varying rates from 50 to 400 words per minute.
   - A. A text buffer of incoming text is maintained in the computer, that can hold up to two hundred pages of text.
   - B. The ability to move a cursor around in the buffer and have the option to spell the next or previous word, speak the next or previous word, number of words, sentences, and paragraphs.
4. Various options for machine scanning of text.
   - A. A page scanner where the computer automatically reads a stack of separate pages of text that are printed on one side at the rate twenty seconds per page.
   - B. A device that can directly scan text from a book.
   - C. The ability to have the computer automatically determine the layout of a page, and to check to see if it contains graphics or pictures and then scan it properly.
5. Special cursor control devices that allow for rapid and efficient manipulation of the text cursor in the buffer.
6. Advanced intelligent editing and text review environment.
   - A. Options for different operational modes for synthetic speech output after the all of the text has been scanned or if text is received on a disk (or by other means).
     1. Continuous speech at varying rates.
     2. Scan (compressed speech where non-essential words are dropped).
     3. Spell the next or previous word at the cursor.
     4. Speak the next or the repeat last of the following items that are next to the cursor: word, sentence, and paragraph (and also be able to repeat the same operation over any arbitrary length of text, for example, the complete file).
   - B. Context search capability.
     1. Search for occurrences of words.
     2. Search and substitute a group of words for another.
   - C. Search for logical occurrences of words. This feature would allow one to search for group of words that have logical relationships between each other. Such as, search for brown cow and grass in the same sentence.
   - D. Search for first or last sentence of paragraphs (topic or summary sentence of paragraph).
   - E. Search for headings.
   - F. Search for phrases, this feature would allow one to search for a group of words, but would allow slight mistakes in ordering of words and the inclusion of extra words or the omission of other words.
   - G. Search for occurrences of words from key word list. Key word list are compilations of important words in a subject group that are associated with a topic of interest. When reviewing many pages of text it is possible to scan through it by just going to areas the have occurrences of words that are in the key word list.
   - H. Generation of multiple key word list.
   - I. The option of having assistance with the spelling of words, by prompting the user after the input of any words that do not match online dictionary entries (also operates during inputting of search parameters).
   - J. Online dictionary, thesarus, and synonym reference.
   - K. Provide information to the user on layout of text on pages, (where the columns of text, graphs, and pictures are on the page).
   - L. Have an advanced indexing and commenting feature where markers and notes can be added anywhere in the text that is being reviewed but are contained in a separate file such that they are only included in the original text on demand. This index file can be searched separately to find an important position in the original text. This file could also be thought of as an overlay to the original text.
7. Various options for storage of text.
   - A. 100 page storage buffer in computer.
   - B. 300 pages of storage of text on built-in floppy drives.
   - C. 2,000 pages of storage of text on hard disk drive.
   - D. 20,000 pages of online storage of text on built-in high capacity optical disk drive which allows access to large data bases.
8. Built-in modem for remote telephone communications.

DESIGN PHILOSOPHY FOR REALIZATION OF THE PORTAREADER

The provided list of specifications were generated with actual implementation in mind. Therefore most of the items could be fulfilled by using technology that is available now or within the next two to three years. It is certainly possible to envision features that will not be realizable for some years, but it appears that potential users understand this and have not generally requested such capabilities. The mapping of the specifications into actual equipment has followed a design philosophy that will hopefully build a device that meets most of the requirements for the lowest cost in the shortest amount of time. These guidelines have provided an optimal path toward implementaion by:

1. Incorporation of modularity into the design of the device to allow for adapability to user requirements and expandability for future enhancements;
2. Extensive utilization of off-the-shelf parts and systems, which allow for reduced development time and cost, and the incorporation of ecnonomies of scale that can only be gained by use of mass produced products;
3. Utilizating state-of-the-art devices and components that provide the best cost/price performance;
4. Use of colaborative efforts with industry that allow for the incorporation of the latest and best technology available.
5. Utilization of special equipment developed previously at the center for hardware emulation to reduce design cycle time;
6. The creation of software solutions over hardware designs whenever possible to allow for maximum flexibility;
7. And maintaining a strict design criteria of easy manufacturability for all aspects of the total system.

It is also important to have a good design environment for the efficient development of the system. This was done by configuring a system that is show in Figure 1. This development system utilizes many of the resources at the RR&D Center. Software can be developed on the VAX or the IBM XT and whenever possible all software is done in the "C" programming language. The system utilizes specialized imaging hardware developed for a previous project.[10,11] This equipment allows for the emulation of a commercial OCR device prior to its design completion.

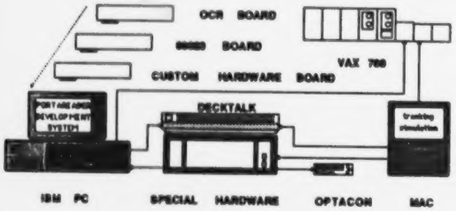

FIG. 1
PORTAREADER DEVELOPMENT SYSTEM

HARDWARE / SOFTWARE IMPLEMENTATIONS

The hardware that was selected for the actual implementation of the PortaReader had to be consistant with the design criteria and meet the specifications in a cost effective manner. To meet these goals, the PortaReader utilizes as many off-the-shelf components as possible so as to gain benefits from larger production quantities. The device was built around a Zenith Z-171 portable computer that is IBM compatible. The Z-171 has been enhanced so to allow the addition of an optical character recognition board, a speech synthesis board, and a custom board that adapts and integrates the system. The text reading capabilities of the PortaReader will be derived from a powerful optical character recognition board that is being developed by a commercial company. This board contains a number of custom chips that attain a new level of performance to cost capabilities not yet seen in the market place. Special provisions have been included into the design of the OCR board to allow the RR&D center to adapt it to the special needs of the target population. These provisions allow the Center's development team to gain access to the raw video data, and to pipe it to a custom board. This custom board, teamed up with a state-of-the-art high speed 68020 micro-processor board, provide special image processing capabilities to allow for tracking feedback and identification of features on a printed page.

FUTURE DIRECTIONS

More work must be done on the software implimentation of the the text editing and review environment for the ProtaReader. This is an area where further simulations are required to more fully understand the human factors involved. It is projected that this work could be completed in the next two years along with alpha level evalutions of the prototype by interested potential users.

CONCLUSIONS

At the conclusion of the development of the PortaReader, a device should be available that will warrent a full evaluation by the Veterans Adminstration. Along with development work, the RR&D Center is actively seeking out commercial entities for technology transfer. It is hoped, that through this process, that a useful text communication environment for the blind will become generally available to the user population.

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Automatic Feature Extraction for the transmission of American Sign Language over telephone lines

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Abstract -

The transmission of visual images, rather than auditory signals using the standard telephone system is difficult because of the bandwidth requirement of a video quality image. This paper describes compression techniques and coding algorithms that generate and encode two-level cartoons from gray-level images for the transmission of American Sign Language at very low data rates. Spatial compression reduces the resolution of the image while preserving the quality of the picture and the intelligibility of the sign. The edges are extracted and the image is thresholded to eliminate the unnecessary information, like clothing, texture of the clothing or hair styling . Each region of the resulting discrete binary image is reduced to its minimal cross-sectional width by applying an image thinning algorithm. An image tracking or contour extraction technique is developed to decompose the image into a finite number of subsets containing complete informations about the shape and size of the image. A contour coding algorithm and a method based on feature extraction and interpolation techniques are applied to these extracted subsets and the results are discussed.

INTRODUCTION

While the telephone system allows a person with unimpaired hearing to communicate at normal speech rates of 125 to 200 words per minute, Telephone Devices for the Deaf do not allow a hearing impaired individual to transmit typed messages at this rate. These systems have the advantage of being usable by completely deaf individuals but they do not allow an experienced typist to exceed a rate of 60 words per minute [1]. Furthermore, it is more difficult for congenitally deaf persons to learn English which is an acoustically based language. The primary form of communication used among individuals of the deaf community is American Sign Language (ASL), a gesture language comparable to spoken languages. Therefore a communication system that would allow the transmission of visual images would be more appropriate for many deaf individuals.

ASL is an independent language that uses movements of the hands and arms as well as facial expressions. The face is used to indicate emphasis, the topic of the conversation or questions. The basic parameters that describe signs in ASL are the configuration of the hands, their orientation, their arrangements, the place of articulation and the movement pattern [2]. ASL is connected to spoken languages by a manual alphabet, called finger spelling, that provides representation for words for which no ASL sign exists. Experimental studies [3] show that an ASL signer can communicate at the same rate as an English speaker.

High resolution video telecommunication systems are the most adequate for this form and for all forms of visual communication. The disadvantages of these systems are their high bandwidth requirement (4MHz for television and 1Mhz for Picturephone, a system that allows voice and image transmission in real time), and their high price. The transmission of visual information over standard telephone channels (3 Khz bandwidth for analog channels and 4800 bits/s to 9600 bits/s for digital channels) reduces dramatically the cost and bandwidth of such a network but requires extremely compressed ASL images. In this project, we investigate a telecommunication system for the transmission of ASL and finger spelling over public switched telephone networks that can be used by the deaf and the hard of hearing. We will describe automatic techniques for the compression of gray-level images to generate cartoons as well as suitable coding algorithms that would significantly reduce the information rate.

PRIOR WORK

Basic studies for measuring the minimum bandwidth for the transmission of ASL were started in 1978 by Sperling [4]. His experiments [5] revealed the minimum spatial resolution needed to interpret ASL and finger spelling. He found that intelligibility was quite high at 21 Khz for ASL and 86Khz for finger spelling but fell off rapidly at lower rates. Pearson's studies [6] on spatial sub sampling showed that deaf communication was very tolerant of PCM quantization distortion. He also worked on temporal sub sampling by repeating fields and showed that performance starts to deteriorate at 15 frames/s. He concluded that just-intelligible communication could be achieved at 100 Kbits/s. Experimental research by Sperling [4], Sosnowski and Hsing [7]on spatial resolution showed that movements could not be defined with an accuracy better than 60x40. The difficulty with the experiments were that this low resolution and consequently the high quantization distorted dramatically the displays and therefore altered the movement.

Since the position of the fingers is the most critical in sign language, several experiments using sensors or miniature lights attached to a glove on each hand have been carried out [8]. Those experiments, also known as point-light displays, showed that communication was possible based only on hand shape. Similar experiments [9] employing feature extraction for the use of motion to define a sign as opposed to the form of the human arm resulted in a high accuracy of identification of the signs and demonstrated that the three-dimensional ASL could be adequately represented in a two-dimensional display. The main difficulty with this method is the dubious convenience of the system, the impossibility to transmit facial expressions and the difficulty of finger spelling. Foulds [10] extracted by hand a set of anatomical sites that are determined to be of importance in ASL and finger spelling and then connected them to obtain experimental stimuli (stick figures). Because this approach is related to the point-light display method, these results confirm previous deductions about the quantization effect.

More recently, Nadler, Letellier and Abramatic [11] generated cartoons of signers using a method based on Gaussian-filtered Laplacian operators. The images are quite intelligible but the bit rate is still too high. Pearson's [12] and Sperling's [13] most recent experiments on cartoon images demonstrated that the data rate is highly linked to the choice of the edge detector that allows the generation of cartoon images. Most of the difficulties in this approach are due to the quantization effects on the perception of the human movement.

COMPRESSION TECHNIQUES

In this study, we propose new techniques for the compression and coding of ASL images that would reduce the bit rate and/or improve the image quality over previously known techniques and to demonstrate that the development of suitable encoding algorithms highly related to the compression algorithms would affect the bit rate.

Pearson, Sperling, Letellier et al. generated two-level cartoons by extracting the edges in the images. The resulting signs are intelligible but low bit rate could only be achieved with very low spatial resolution images which are shown to be quite disturbing to the user. Letellier et al. [14] addressed this problem by increasing the spatial resolution but, as a result, they highly increased the data rate. Our study also involves cartoon images generated from grey-level images using edge detectors as well as valley detectors.

The algorithm selected for the extraction of the contours in an image is a valley/edge detector developed by Pearson [12]. In his last experiments, he reported that valley-based detectors brought out important features of the human face and hands better than step edge detectors. The valley detector implemented in this study has an optimal response to valleys and residual responses to edges, when convolved with the image. Step edges are necessary for the extraction of smoothly curved, uniform reflectance objects and the valley operator allows the extraction of the outline of the object only as opposed to double lines boundaries, as in the case of an edge detector. Furthermore, this valley/edge detector is a logical, highly non-linear operator that is tolerant to noise, can make fast decisions and has a small support (for faster computation). The valley detection is followed by a non-maxima suppression for the generation of one picture element thick contours.

CODING TECHNIQUES

Contour tracking

A contour tracking algorithm is applied to the two-level cartoon images generated by the valley detector. This tracking process retains only the pixels that are necessary to reproduce the geometric structure of the image contour. The contour of the binary edge-detected image is broken into a finite number of separate connected edge pixels called *tracks* containing complete informations about the shape and size of the image. Figure 1 shows an image contour and the corresponding tracks. Each track has a minimum length of 2 picture elements. This requirement reduces the noise resulting from the contour extraction process.

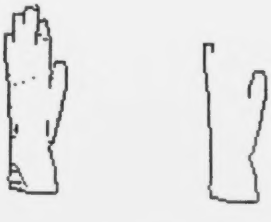

Fig. 1 - a) Contour of a hand
b) One track of the contour

Contour coding

The organization of the image into tracks allows the implementation of an efficient contour coding algorithm. The contour and point coding algorithms seem to be more suitable to encode two-level cartoon images because of the small percentage of the points (about 2% for a 128x128 picture) that describe the image contour. Each track of the contour is coded separately. The informations contained in each track are the coordinates of the edge and one of the eight quantized edge directions used to trace it. The coding consists of conserving both the coordinates and the direction for the first edge of the track and coding the remaining points of the track using only the direction information of each point in the track.

The efficiency of this coding algorithm is improved by minimizing the number of tracks in the image since the coordinates of the first point of each track needs always to be transmitted. Two methods were conjointly used to reduce the number of tracks. The first one consists of replacing the non-maxima suppression algorithm in the valley detector with a thinning algorithm implemented in this study. This method results in more continuous contours due to a *line connection* algorithm included in the thinning algorithm that checks first if a point is not the only connection between two segments (or tracks) before suppressing it. The second method results from the observation that a large number of tracks contains only 2 points. These tracks correspond mainly to the contour and features of the face. Modifying the algorithm so that only one track groups all the two-point tracks increases by 20% the efficiency of the contour coding algorithm. This contour coding method shows an improvement of 3:1 and 4:1 compared to hierarchical (quadtree or block coding) or reconstruction mapping (run-length) methods.

Feature extraction

The contour coding algorithm reconstructs the image without any loss of information. However, it is possible to reduce the bit rate by coding only feature points on each track of the contour. The method consists of extracting the feature points from the image contour, coding them before transmission and then at the receiver fitting this set of data points to a curve (or track) using linear or higher order polynomial techniques. The image generated with this technique approximates closely the shape of the transmitted binary contour as illustrated in figure 2.

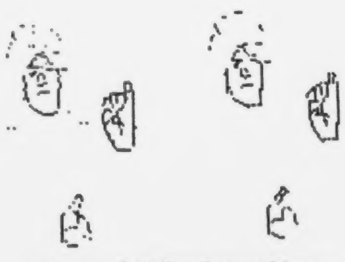

Fig. 2 - a) Valley detected image
b) Reconstructed image using linear interpolation

The feature points lay at locations where a significant change in the curve shape has occured. These points correspond to the minimum and maximum of the curve and will be referred to as peaks and valleys (figure 3). To reduce the distortion of the image and optimize the coding algorithm, additional points are extracted between peaks and valleys if a minimum distance is not observed. Another method, called the constant interval method, consists of extracting from each track of the image contour the points located at an equal distance from each other. This method results in fewer points but in a greater distortion of the contour since the points carrying informations about the direction change of the curve can be missed.

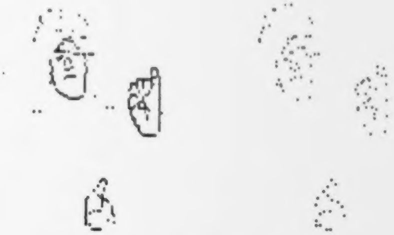

Fig. 3 - a) Valley detected image
b) Extracted peaks and valleys

RESULTS

Preliminary experiments have shown that a 128x128 image can be specified with a maximum of 1800 bits when the contour coding method is used, resulting in a data rate of 27 kbits/s with 15 frames/s. An average of 6200 bits were necessary to code the same image when the quadtree algorithm was used. The coding of the feature points results in only 1200 bits/image or 18kbits/s for 15 frames/s. The addition of the track minimization algorithm results in 1530 bits/frame or 23 kbits/s (for 15 frames/s) for the contour coding and 1000 bits/frame or 15 kbits/s (for 15 frames/s) for the point extraction method. These results are based only on intraframe coding. We expect to reduce the data rate further by using interframe coding techniques.

CONCLUSION

Different compression and coding methods have been developed for the representation of perceptually significant features, in cartoon form, from grey-level images of a signer. Methods of evaluating image quality or digital compression techniques developed for non-distorded, almost perfect reproductions of the grabbed image, can not be applied to the cartoon images being investigated. The methods that are appropriate for our needs should consider the human perceptual system and consist of measuring the intelligibility of the cartoon image versus bandwidth trade-offs. Among the investigated techniques, the feature extraction algorithm seems to lead to the best data rates though the received image is not an exact replica of the transmitted image.

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A COMPUTERIZED OPTACON TUTOR

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ABSTRACT:

We report on a microcomputer system designed for the assistance of blind persons' Optacon training. Reading printed text with the Optacon at a reasonable speed needs intensive training. The OptaconTutor is an interactive system that offers reading training at variable levels of performance. Reading is not restricted to predefined fonts; arbitrary fonts can easily be designed. The system may be used by untrained as well as by advanced Optacon readers.

INTRODUCTION

The Optacon is a reading device that enables a blind person to read printed text intended for sighted persons without any specific text preparation or transcription (1). It consists of a small hand-held camera and a vibrotactile display of 24-by-6 pins. The pins vibrate to produce the tactile version of the optical pattern the camera 'sees' with its photosensitive area of 24-by-6 elements. When moving the camera across a light-and-dark print pattern the user can feel the respective vibrotactile pattern moving across the tip of his lefthand index finger which he has placed on the display.

The use of the device is not easy. A person needs intensive training and experience to gain appropriate reading rates. After a 9-day program the average rate is 10 to 12 words per minute (2), and advanced readers may achieve 30 to 50 wpm (3). For just a few certain individuals rates of up to 100 wpm have been reported (Craig and Moore & Bliss cited in (4)).

There are two skills the Optacon beginner must train: to identify characters and character strings from their vibrating patterns that are passing from right to left underneath his fingertip, and to lead the camera accurately over the text lines. By scanning a printed text line by line, the camera has to be moved continuously so that the patterns are correctly positioned on the Optacon display. It has to be kept exactly in line, and at the end of the line it has to be repositioned to the beginning of the following one. According to the manufacturer's training manual (5,6) the recognition of a specific pattern is learned by its repeated presentation, first as single letters, and - at a more advanced stage - embedded in words and sentences. At the beginning of the course, the camera operation is executed solely by the teacher and only gradually taken over by the student.

To support the process of learning, we have designed and realized a microcomputer system, the 'OptaconTutor' described in the following.

TECHNICAL BACKGROUND

For several years we have worked with the Optacon as a tactile output device for an Apple IIe microcomputer. The Optacon is connected to the computer by a special interface we have developed in 1983 (7) which replaces the Optacon camera by a 'software camera' that can be moved across the information in the display storage. That feature conveys the impression as if the software camera were moved across the screen in either of the directions up, down, left and right. The movement may be controlled by a person using joystick, mouse or data tablet, or automatically by a program. The basic software transfers to the Optacon characters from the text screen as braille patterns, and patterns on the graphic screen are reproduced directly by mapping a 24-by-6 pixel section - the Optacon 'window' - to the 24-by-6 pin array of the Optacon display. Zoom functions allow the user to enlarge the window for overviews, and several additional functions support the orientation on the monitor screen. Thus, a text stored electronically in the computer can be read in braille on the Optacon (7). The opportunities of the graphics part of the interface are an integrative part of a computer aided drawing-system for the blind (8,9). Both text and graphics features permit a scanning of the text files either in braille or in any ink-print font. The computer gives the user full support to stay in line and to choose his individual scanning speed.

COMPUTERIZED OPTACON TRAINING

The basic idea of the OptaconTutor is to enable a teacher to assemble computer aided lessons and courses for Optacon training simply by creating appropriate text files. The student will work with these files in various exercise modes which may be selected by the teacher according to the student's reading skills. The whole system consists of a teacher's as well as a student's module.

The teacher's module

The teacher's module provides functions for creating, arranging and managing courses and fonts. It can be used by sighted and by blind persons.

The 'font manager' allows to define and edit print fonts, Braille dot patterns and arbitrary shapes, and to store and manage those fonts in a font data base. The size of print characters and the distribution of dots in Braille patterns are adjustable, and so is the distance between adjacent characters including proportional spacing for print.

The 'course manager' offers functions for arranging and rearranging exercises, for entering and for editing the underlying text files, and for storing and managing the various exercises in a course base. A course is defined by specifying several parameters and attributes.

Text representation functions

One attribute refers to that text file which contains text, words or characters in a special arrangement and order required for the course. Others define the type of representation on the Optacon display: braille or print, font, size and spacing.

Scanning modes

The scanning attribute determines whether the camera movement is controlled automatically or manually by joystick or mouse . Whereas in the automatic mode the constant scanning-speed can be varied, the non-automatic mode offers a variation of the speed range.

Manually controlled scanning can be supported by setting the 'align mode' in which the software camera is kept automatically on the text line. That means, the computer ignores small vertical deflections of the scanning movement caused by an inaccurate use of joystick or mouse. The 'align function' should be turned on when an electronic text stored in a computer is being read. For training purposes the operation of the mouse may simulate the operation of the true camera when the 'align function' is turned off; accurate camera movement, however, may be trained more efficiently with the original camera.

The 'stop' attribute controls another helpful mode. It defines whether or not the software camera is automatically repositioned to the beginning of the following text line when reaching the end of the current line.

Finally, a special 'browsing mode' may be chosen that causes the software camera to skip successive blanks while scanning a text.

Evaluation parameters

The student's performance may be measured in various parameters such as stop watch and amount of characters or words read in a definite time interval. Such features open up simple ways for various evaluation purposes, e.g. for determining the legibility of characters, fonts and Braille patterns or for evaluating hypotheses on reading strategies and reading improvement.

The student's module

This module contains the actual training program, the OptaconTutor. For unaided training the student selects a course from the course base. The 'trainer' may also be used simply for reading without using a course program. Any text file may be read in any available print font or Braille dot pattern contained in the font base.

Support for course design

The OptaconTutor supports the design of three basic types of training units. In the 'recognition' unit single characters or words are offered for reading, either in a constant speed or in a user-controlled scan. After having recognized the string the student is requested to type it on the keyboard. If the entered string does not match with the given pattern, the wrong characters will be indicated. The test then will be repeated. As soon as the input is correct, the next pattern in the text file will be presented. For each single string the recognition time and the number of unsuccessful trials is registered.

The recognition performance can be improved in the 'string search' unit. Here, charcters, words and texts of up to 80 characters in length lie embedded in different contexts. The student has to take to reading the given text and indicating each occurrence of the search pattern in the text. The indication is checked by the computer and a corresponding message is given for feedback. The number of right and wrong indications, the number of lines read and the time used are registered.

A third unit serves for the determination of the reading speed. Time, length of text and the number of words are registered.

In all three units the text may be presented in Braille patterns or in the different fonts contained in the font base, and it may be scanned either automatically at a constant speed or the speed may be controlled by the user. The levels of difficulty may gradually be increased, and a stepwise training is possible.

CONCLUSION AND PERSPECTIVE

In the Braille version of the OptaconTutor a scanning speed of about 120 wpm may be achieved while the scanning of print patterns is significantly slower. Thus we have developed a reasonable tool for reading text stored in the Apple with the Optacon if we use the Braille representation. For reading text in print fonts, the system is only good for beginners, but too slow for more advanced readers who want to improve their performance of 30 to 50 wpm. Therefore a faster version of the OptaconTutor realized for an IBM-PC is in preparation. That program will allow a reading speed of more than 100 wpm in print fonts.

A reading rate of 50 wpm seems to be the speed barrier for most Optacon users. It might well be that the reasons are similar to those which prevent poor paper Braille readers from better reading performance. Grunwald, cited in (8), argues that most Braille readers read slowly because they identify words letter by letter, and not as whole words. We expect to find that this is true also for reading vibrotactile print patterns that are moving across the Optacon display. And we hope that the OptaconTutor will help many Optacon readers to improve their reading skills.

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Deaf Persons Deserve Better Than a TTY for Communication

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ABSTRACT

Deaf persons most commonly use teletypewriter (TTY) or an equivalent device for telecommunicatiog today. These devices function on the premise that the people communicating can type, compose, deliver and understand written English efficiently. Needless to say, because of the language difficulties of deaf persons, the premise proves false, and the TTY is often used as an emergency rather than a social device. In this paper an alternative communication software for use on the MacIntosh microcomputer is presented. This software allows the deaf people to send and receive pictures and/or text simultaneously. The users can store or modify their own or other person's compositions. The entire program is menu driven and the manual is also written pictorially.

In the preliminary trials deaf people enjoyed sending cartoons and personal messages which they could not do on a TTY.

INTRODUCTION

Communication with then English language spoken or written is difficult for congenitally deaf and other handicapped people who may be primarily processing information visually and spatially. The problem of English comprehension is well documented in literature [1]. This problem is primarily due to a lack of auditory feed back during prelingual years, which is considered essential for spoken language development [2]. Various studies using computers with computer graphics suggest that there is tremendous potential in using these devices to benefit deaf persons [3],[4]. To this date the use of computers with deaf persons has been limited to alleviating their academic skills and not for interpersonal communication.

Telephone forms a vital part of the business, personal and social lives of the hearing people's day; for 5 million or so congenitally deaf persons the telephone has no benefit. TTY, for the first time, provided a potential communication link for deaf persons. However, their English language difficulties means that they can or often misunderstand the communicated information and long social exchanges such as those amongst the hearing do not usually occur on the TTY. Modern microcomputers with strong graphics and modem links over the telephone remove the restrictions of communicating via text and alternative communication forms can be explored. While English text is difficult for deaf people, graphic and labeled pictures with limited text are not [5]. Deaf persons enjoy comics and cartoons and their own language, American Sign Language, lends itself to graphical representation. The development of the concept of the software is based on this observation.

BACKGROUND

The telecommunication devices of the deaf (TDD) of today are basically TTY in the sense that they heavily favor text communication no matter in which form they are developed. There are text to voice devices and text to text devices [6]. There is some effort to reuse picture phone technology with reduced bandwidth so that sign language can be communicated through a video link [7],[8]. Most of these devices are in development stages. Commercially only teletypewriters have been sold successfully, the reason for this is primarily historical. When electronic terminals (CRT) using ASCII replaced old BAUDOT terminals, these latter became surplus, and some enterprising people refurbished these for use by deaf persons and BAUDOT code became a default standard for deaf communication. This is changing with ASCII switches available on most modern TTYs for deaf persons. However these devices still require communication in English text without graphics.

There are increasing numbers of states in the country which provide assistance for deaf people in purchasing or leasing communication devices. The idea in developing the software using graphics was to see if the existing microcomputers could be used to provide an alternative means of communication, and further, if such a device was available, would deaf people find it useful.

SOFTWARE DESIGN

The computer selected on which software was developed was the APPLE MacIntosh @. Even though an earlier version of the software was developed on an IBM @ PC [9], it was decided that the graphics and the ease of use of menus and mouse on the MacIntosh would make this latter computer more useful. The software design could capitalize on the routines available in the MacIntosh tool box, the documentation inside MacIntosh Vols I-II and associated routines supplied by the Apple Company. Since the entire system is mouse driven, it was decided to use their single button mouse as the user interface device [Fig 1]. The driving force behind selecting the screen format, once again, was the visual-spatial communication profile of the deaf user. It was decided that both communicator and the communicatee would prefer to see their outgoing and incoming information. This decision was based on the observation that for error-free communication, most congenitally deaf persons preferred printed documents of both the received and transmitted text. Hence, the computer screen was devided into the outgoing and incoming message screens. Each of these screens were further subdivided into the current and past screens. The past screens provided the context for the conversation. The graphics on each screen was organized so that comic book type of information could be exchanged [Fig 2]. The first person (sender) in the "out" window composes his story and transmits, as shown on the top of the figure, which appears in the second person (receiver)'s "in" window, as shown in the bottom of the figure. In the meantime, if the second person was composing something in his or her "out" window it would be transmitted into the "in" window of the first person. The transmission code is cleverly designed to provide this handshake mode over the telephone line. It was recognized that if there were commonly used graphics, the user may want to save these in graphic files for recall. To accomplish this, three save files (labeled animals, minerals & vegetables in figure 1) were created. Each file had five subcategories and four pictures in each category so that the user could save a total of sixty pages before having to overwrite. These file title and subtitle names in the menu can be changed by the user to a name of their own choice. The directory management is done through the file menu while the information composition is accomplished through the draw menu. Depending on the modem used, appropriate telephone data transmission band rate can be set by the user [Fig 1].

The user manual was created to be rich in graphics with sequences supplied in easy transferred syntax so the deaf users could use the manual with ease. Both figures 1 and 2 are pages out of the user's manual.

RESULTS & DISCUSSION

The software developed was tried with four deaf persons. Two were husband and wife and the other two were close friends. Four MacIntosh computers were connected in two pairs and the deaf persons were provided with the manuals. None of the users had ever used a MacIntosh microcomputer before, two had never used any computer before. They were shown the movement of the mouse. Within fifteen minutes all had acquired enough proficiency in the use of the software by transmitting and receiving information to each other. It was close to Valentine's day and the husband and wife had a field day sending flying hearts with messages! Something they could never have done on their TTY. The present software is static in communicating expressions, and therefore is only a level better than a TTY. Currently an animated version of the device is being developed.

CONCLUSIONS

Both the user's manual and the user-interface rely on the strengths of deaf persons, viz. their vision. It provides the cogenitally deaf persons with a medium to be creative while interacting socially even though separated by great distances; the software is easy to use and reduces the frustrations of communicating on a TTY.

ACKNOWLEDGEMENT

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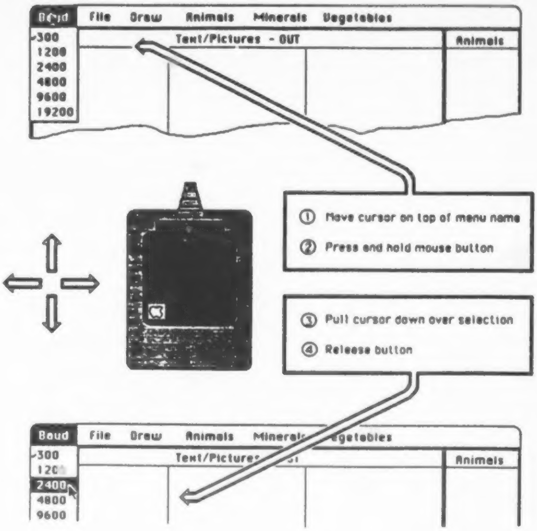
Making selections from menus



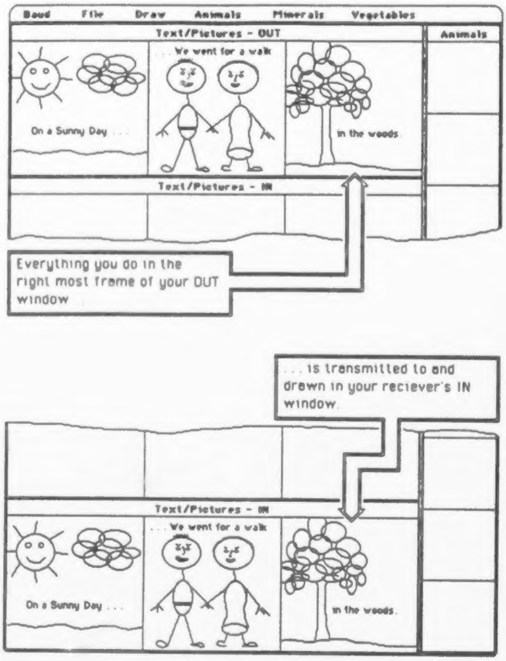
① Move cursor on top of menu name

② Press and hold mouse button

③ Pull cursor down over selection

④ Release button

Communications with the GCD



Everything you do in the right most frame of your OUT window

... is transmitted to and drawn in your reciever's IN window.

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EXPERIENCED TECHNOLOGY USER SURVEY: DESIGN/OPERATIONAL FEATURES FOR BLIND READING AID

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ABSTRACT

A survey of over 150 blind and visually impaired individuals has been conducted to help establish design and operational features for a portable reading aid for the blind (1,2). To gain additional relevant information for the design of a reading aid a survey of a subpopulation from this group is being conducted. The individuals to be included in this survey are those who reported having substantial experience with technology, including experience with existing reading machines (specifically the Optacon, Stereotoner, and Kurzweil Reading Machine, or a computer adapted to meet some reading needs). It is felt that this subpopulation offers a unique human resource that can be utilized to gain valuable information necessary to design a reading machine that best meets the needs of the blind and visually impaired.

The experienced user questionnaire has been pretested and, based upon that experience, modified. This paper describes the questionnaire, relevant findings of the innitial questionnaire, and preliminary findings from the limited number of experienced users sampled to date. Of particular interest are the findings that cost and weight (of a portable reading aid) are important considerations for users and the critical values appear to be a cost of no more than $5000 and a weight of 20 pounds or less.

INTRODUCTION

An estimated 500,000 individuals in the United States are totally blind, while another 1.5 million are legally blind. These numbers include over 200,000 veterans. Clinical experience and numerous research studies (for example, 3) indicate that access to printed materials is one of the most common problems reported by both blind and partially sighted individuals. The inability to gain access to printed materials severely limits employment and educational opportunities, as well as day-to-day activities.

Since the early 1970's numerous attempts have been made to develop reading aids for blind individuals. Several of these attempts have become commercially available products (i.e, the Optacon, Stereotoner, and Kurzweil Reading Machine (KRM), although the Stereotoner is no longer marketed). While both the Optacon and KRM have received some consumer support they have not met all consumer needs, and it is generally agreed that alternative reading aids are needed. The current project is one step in a more global project to develop such an aid.

BACKGROUND

In 1986 the current project was initiated with the goal of establishing design and operational features to be used in the development of portable reading aids for the blind. A key component of this project is an extensive telephone survey of blind and visually impaired individuals to gain their input on specifications for portable reading aids. The individuals responding to this survey represented a heterogeneous population in regards to current employment, reading aids utilized, experience with computerized reading aids, veteran status, age, and background.

Among other findings the survey revealed that potential users of portable reading aids were very concerned with the cost and weight of any proposed reading aid. It was not possible to determine, on the basis of this questionnaire, how such user concerns might interact with the performance of an aid. For example, if the proposed reading aid offered substantially greater performance at greater cost and more weight would it be acceptable? And, if so, how much cost and how much weight would be considered acceptable? On the basis of these results and the questions these data generated, a second questionnaire has been developed and is being administered to a sample of experience users of reading aids and adapted computers.

METHODS AND MATERIALS

An extensive, telephone administered questionnaire has been developed and pretested on a small sample of experienced users of reading aids and computers adapted for the needs of blind and visually impaired computer users. It is currently being administered to a selected group of experienced users who were identified in our first study. The questionnaire solicits detailed information from each subject on numerous topics including:

1. General background with reading aids and computers.
2. Employment relating to reading aids and computers.
3. Reading needs.
4. Levels of satisfaction with current reading aid(s).
5. Resources for purchasing reading aids.
6. Ratings of the desirability (or undesirability) of possible reading aid features. and
7. Desirability of various ancillary features such as automated magazine/book production, remote reader services, etc.

Subjects

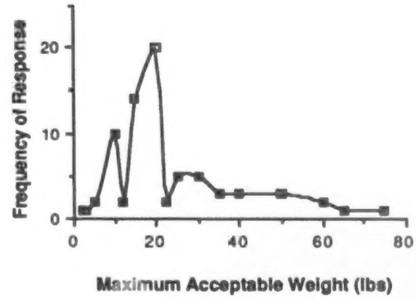
Fifty experienced users of reading aids and/or adapted computers, who have previously indicated their willingness to participate in this study, are being administered the experienced user questionnaire. Each potential interviewee has had at least one year of experience with either a reading machine or an adapted computer that allows access to text stored on a computer or in print form. In addition, each subject previously participated in our initial survey and volunteered to participate in this study.

RESULTS

The initial telephone survey identified a sample of 75 individuals who have had at least one year of experience with adapted computer aids. Approximately 60% of this sample has one or more years experience with the Optacon, 54% one or more years experience with an adapted computer, 30% one or more years with the KRM, and less than 2% have one or more years experience with either the Ready Reader, Omni-Ready, or Stereotoner. Many subjects had experience with two or more reading aids. Two out of three subjects were not satisfied with their current reading method(s). Reasons for this dissatisfaction included inefficiency, lack of privacy, lack of availability, and inability to read a wide variety of formats. None of the respondents reported having a completely satisfactory method of gaining access to printed materials, nor did any combination of methods (i.e., readers and reading aid) meet all their perceived needs.

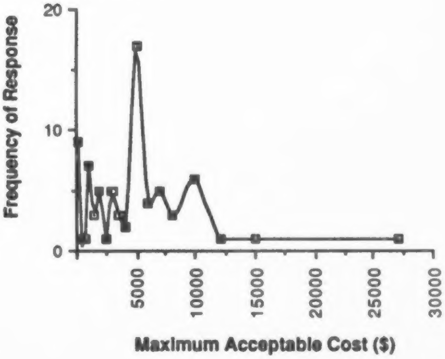
When asked about design considerations (of a hypothetical, portable reading aid) weight was a major concern among the experienced users. Fully two of every three felt that 20 pounds was the greatest acceptable weight (see figure 1).

Figure 1. Response frequencies of 150 subjects regarding the maximum acceptable weight for a hypothetical, portable reading aid.



Cost was also a major consideration, as shown in figure 2. A cost of $5000 was stated by 7 out of 10 individuals as the maximum acceptable cost for the proposed reading aid. In regard to cost, it is important to note that while three out of four subjects were employed, only about one third felt that their employer could or would be able to help purchase a reading aid, even for job related tasks.

Figure 2. Response frequencies of 150 subjects regarding the maximum acceptable cost of a hypothetical, portable reading aid.



DISCUSSION

A telephone questionnaire has been administered to over 150 blind and visually impaired individuals. Data gathered in these interviews provided detailed information on the subject's demographics, their current methods of reading, their satisfaction with these methods, and of the features they considered important in designing new reading aids. On the basis of these questionnaires the variables of cost and weight, appear to be critical considerations in determining how many people use a reading aid. It was also evident that satisfaction with any particular reading method (whether it be technological or a human reader) was influenced by a wide variety of factors including privacy, efficiency, convenience, and accessibility.

The demographic data revealed that our sample included a significant subpopulation of individuals (N = 75) with extensive experience in using reading machines and adapted computers. The average length of familiarity with computer technology (for this subpopulation) was over 5 years. The reading machines used by these individuals included the Optacon, Kurzweil Reading Machine, Stereotoner, and various computers adapted to meet some reading needs. This collective experience, with so many different reading aids, makes this subpopulation of extreme interest. Accordingly an experienced user questionnaire has been developed to gain additional information from a sample of at least 50 experienced users regarding their perception of various design considerations including: cost, weight, scanning methods and feedback options (i.e., auditory), data storage, and other variables. The questionnaire has been pretested and is being administered. Insufficient data has been gained, as of this writing, to warrant any conclusions, however the trend of the data supports our previous findings that cost and weight are critical variables. The design of a new, portable reading aid should include consideration of these variables since they reflect the needs of user population, and will likely influence the acceptance of the aid. When completed, the results of the experienced user survey will be published.

CONCLUSIONS

Cost and weight are perceived by both experienced and inexperienced blind and visually impaired individuals as critical factors in determining the acceptace of a portable reading aid. Preliminary findings indicate that cost should not exceed $5000 and weight should not exceed 20 pounds. A questionnaire is being administered to a selected sample of 50 experienced users of reading machines to determine how cost and weight variables interact with hypothetical performance factors. This information will help determine the effect (on user acceptance) of any trade-offs that must be made in designing portable reading aids.

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USE OF PRESSURE ZONE MICROPHONES WITH FM AUDITORY TRAINING EQUIPMENT TO IMPROVE SIGNAL TO NOISE RATIO

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ABSTRACT

Many hearing impaired listeners have difficulty understanding speech in a background of noise when using a conventional hearing aid. In recent years a small FM transmitter and receiver are often employed to help hearing impaired listeners hear the primary speaker in noisy environments. This study analyzed the influence of different types of microphone design on the speech recognition of hearing impaired listeners in a simulated small group setting within a closely controlled reverberant room. Results indicated that conventional hearing aid microphones were rated as producing poorer speech quality while other microphones, used with an FM system were rated highest by listeners.

INTRODUCTION

All sound rapidly loses strength when traveling over even short distances. This explains why speech is understood more clearly over a short distance than a longer one. The propagation of high frequency sound, so critical for speech intelligibility, is more affected by distance than sounds in the lower frequency range. If background noise is present, the effects of distance are even more pronounced (Kuhn, 1980). Normal hearing listeners are apparently able to filter background noise by using little-understood neurological processes. Hearing aids do not filter out background noise and even modest amounts of such noise, while merely annoying to the normal hearing listener, is completely unacceptable to most hearing aid wearers.

The problem, stated succinctly, is that small hearing aid microphones cannot be made with enough directionality to exclude all competing environmental sounds. The resulting amplified mixure of competing sounds only increases the level of the overall sound pattern. FM transmitter/receiver units (commonly called auditory trainers) have been used with considerable success in educational environments to help children hear their teacher's voice above the background of other children and environmental noise in the school setting. Recently there has been interest in using such equipment to help hearing impaired adults who have difficulty in noisy environments such as business meetings or lecture halls. The principles of this equipment are simple, a microphone is attached to the person speaking or placed in a convienient location and connected to a small FM transmitter which emits a signal picked up by a small receiver worn by the hearing impaired person. The signal is either delivered directly to the hearing impaired listener's ear via a small earphone or to their hearing aid for further amplification.

The purpose of this study was to evaluate four types of microphones in a simulated noisy conference room to discover if any significant advantage accrues to using specialized microphones in such environments. In addition, the study was designed to evaluate the general effectiveness of FM equipment in this environment compared to using a hearing aid without additional equipment.

BACKGROUND

Effects of Noisy Environments

Reverberation has been found to significantly reduce speech recognition by hearing impaired listeners (Bess and McConnell, 1981). At any given time, the sound pressure at a listener's ears is a combination of the sound directly from the speaker's lips and those due to the repeated reflections of the original sound wave. Finitzo-Hieber and Tillman (1978) showed that hearing impaired listeners were much more sensitive to the effects of reverberation than normal hearing subjects. In a reverberant room the effects of speaker babble upon the speech perception of hearing impaired listeners would be to reduce frequency selectivity and spatial selectivity of signal vs noise (Nabelek, 1980). Thus in the typical reverberant conference room it is predictable that a hearing impaired listener will have considerable difficulty following speakers, especially when there are several people talking at once. In actual fact, most clinical audiologists meet numerous clients with a primary complaint of an inability to function in small group and noisy settings.

METHODS

Subjects

Three groups of subjects were evaluated; ten with normal hearing, ten with sloping losses with a pure tone average of 45dB HL at 500, 1K & 2K Hz, and ten with flat losses of 55 dB or more.

Stimuli

Preparation. Stimuli employed were specially prepared versions of the NU-6 (Auditec) half-word lists. Special test recordings were made in quiet and in noise in a reverberant room normally used for small conference meetings. Reverberation time for the room was calculated using

Sabine´s(1957) formula (T=3.66 sec.). The pre-recorded word lists were played on a high-quality cassette deck, through a 10 inch speaker located at head level in the approximate position a talker´s mouth would have occupied at the conference table. Four column speakers were placed in the corners of the room to produce a uniform field of multitalker background noise at 50 dB SPL. The microphones were arranged in the center of the table except for the hearing aid microphone which was located on a dummy head in normal hearing aid position. The dummy was "seated" across the conference table from the simulated talker. Recordings were made from three of the four test microphones (PZM1, PZM2, Omni) via an FM transmitter/receiver onto a cassette tape deck. The hearing aid microphone was connected directly to the tape deck via a preamplifier (i.e the microphone pick-up did not pass through the FM system as with the other microphones). The "artificial talker" was placed in 4 different recording locations relative to the microphones (0, 45 & 90 degrees azimuth and far-field). Recording level was calibrated to 60 dB SPL (Re: calibration tone) at the 0 degree azimuth position. Thus at this position the Signal to Noise ratio was +10. The S/N ratio varied as the speaker was moved about the room so that, at the farfield position, the S/N ratio was measured to be approximately 0 dB HL. This was done to simulate an assured, consistant speech effort on the part of a talker at various positions. Recordings were made both in quiet and with 50 dB of noise. Thirty two tapes were produced (4 speaker locations X 4 microphones X 2 noise conditions).

Procedure

Subjects listened to the stimulus tapes under headphones (TDH-39). Stimuli were presented at MCL. Subjects were scheduled for two, one hour listening sessions. In each session, they listened to 16 of the prerecorded lists in random order plus 4 randomly selected additional lists for reliability checks. Subjects wrote down on a score sheet the words they heard. Trials were scored as a percentage of correct responses. In addition, subjects ranked each trial of 25 words on a scale of 1-5, with 1 indicating a very clear, easily understood tape and 5 indicating that they could understand almost nothing.

RESULTS

As would be expected, group means were significantly different across subjects (69.76%; 22.65%; 48.82%). Similarly, average scores in quiet and in noise were significantly different (31.27% in noise, vs 66.34%). An ANOVA indicated, however, that there were no statistically significant differences in scores reported between microphone types. Rating scores indicated, however, that subjects consistantly rated the PZM microphones superior (average rating=1.7) to the omnidirectional (AR=2.3). The hearing aid microphone (AR=3.5) was rated inferior in almost all conditions, especially in a background of noise.

DISCUSSION

The most striking and consistant pattern arising from the data is that the hearing aid microphone condition produced the lowest word discriminations scores for all subject groups, for all conditions. Additionally, it was consistently rated as the poorest in understandability for all microphones for all subjects in all conditions. The differences noted in objective testing, while not statistically significant, are within the clinically accepted range of significance for recommending one hearing aid over another (15-20 %). The trends in the data certainly support the suggestion that microphone type might influence speech recognition performance in hearing impaired listeners. Additional testing will be needed to achive the level of statistical power necessary to confirm these trends, however.

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A BLIND STUDENT IN A REGULAR CLASSROOM
USING A COMPUTERIZED PEN-AND PAPER SUBSTITUTE

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ABSTRACT

The paper describes the new computerized method that we have developed for mainstreaming purposes. We report on the four-year experience we now have with a blind girl who successfully attends a regular class with the help of a microcomputer system that serves as an easy-to-handle substitute for paper, pen, ruler, compasses and protractor. The teachers get the work for all subjects including geometry printed out without being involved in the procedure, none of them knowing braille; they can watch the student at work and can use the system for preparing exercises and written tests to be worked out by the student.The information is shown on a tactile and a monitor screen simultaneously. The procedure is highly flexible and economic as only such material has to be prepared that is actually required in the classes. It proved of decisive advantage that the texts may shortly be made available to the blind student.

INTRODUCTION

Integrating a blind student in a regular school generally requires a considerable amount of personal and organisational effort of all individuals involved. An essential portion of this effort can be traced back to the transcription of written material from braille to inkprint and vice versa. The traditional way to handle the problem is to have an additional special teacher or at least a person knowing braille who is responsible for such braille transcriptions in the daily school work. This, of course, needs considerable organisational coordination for the regular teachers. And even if they learn braille, their work will be delayed significantly by the preparation of texts in inkprint as well as in braille. Such extra burdens usually play an important role in the argumentation against mainstreaming blind students. In the following we give a description of the new computerised method we have developed to enable a blind student to mainstream in the regular class of a school where none of her teachers knows any braille.

STARTING CONDITIONS

In 1983, a ten-year-old blind girl was accepted as a student at a regular high school in southern Germany. She had good knowledge of reading and writing German contracted braille, and her tactual perception of drawings and geographical maps was well above average. From her first day in high school the student switched from paper braille to an electronic substitute for pen and paper realized by a microcomputer system. The system consists of an Apple IIe microcomputer with two disk drives, a braille keyboard, a volatile braille display with 20 characters in line, a matrix printer Epson RX80, and an intelligent piece of software, the BrailleButler system (1), which melts these hardware components into an easy-to-handle, unique pen-and-paper substitute. A special braille embosser attached to the computer can produce paper braille from any text that is entered into the computer. Due to the lack of financial support we have so far worked without such a braille printer. Braille display and braille keyboard are integrative parts of a text-storing device, the VersaBraille. Except for the portable VersaBraille, one set of these devices is installed in the classroom and a second at home. The VersaBraille, weighing 10 lbs., is carried by the student every day from home to school and to other classrooms for special subjects as biology, geography or music. In these rooms where there is no computer available, the VersaBraille, which offers only limited editing functions, serves as a note book. The notes are stored linearly on tape cassettes and transferred to the main system later if they need such further treatment.

We took special care that the student can handle all the apparatuses and their functions on her own. As a consequence of that principle we placed a printer as an integrative part beside the computer. The significance of such 'simple' organizational arrangements should not be underestimated: it is with great astonishment that we see certain cases now where, for fear of damage, the equipment is locked away in a specific room to which only one certain teacher has the key. Such overprotection consequently leads to organisational obstacles that only end up in the anachronism of avoiding the use of the devices altogether.

ELECTRONIC PAPER AT HOME AND IN SCHOOL

The basic method in our approach is to provide the student with electronic paper where the information is distributed spatially (2). Texts and text books are stored on diskettes. The hitherto enormous transportation and storage problems of the quite sizable and heavy paper braille books are thus eliminated. One diskette is assigned to each subject. Different working texts are distinguished and classified by standardized names consisting of a keyword specifying the type of text, e.g. 'home' or 'school' (for home or school work respectively) in combination with the date.

Computerized pen-and-paper substitute

An essential part of the student's equipment no doubt is the software system BrailleButler which was especially designed for blind-sighted communication. One of the main advantages of the BrailleButler system is that it provides techniques for treating a text as if it were spread out on a paper surface. The student views the text through the tactual screen with braille characters, whereas the sighted teacher and any other sighted person like classmates or parents sees it through the screen of the computer's CRT-monitor. Both "look" through a window on the same text document, line by line, character by character, and simultaneously if they want to. The difference lies in the size of the window and the character representation: the visual monitor screen with 24 lines of 80 characters in print font versus the tactual braille screen with one line of 20 braille characters. To obtain unique representations in print and in braille each character of the ASCII-code has a unique braille representation. As six dots in the basic braille pattern are not sufficient to represent all 96 ASCII-characters, capital letters and four other characters are represented by vibrating patterns.

Despite the small size of the braille screen, the system enables the blind student to explore the text and take advantage of its spatial distribution. The electronic paper is scanned by moving the window of the tactual screen either along a line or vertically from line to line. These movements are provoked by moving keys or by the deflection of a joystick. In particular, the possibility to move fast in either direction is suited for getting overviews 'on the fly' by vertical and diagonal scans, features that are commonly used when reading paper braille (3). The student actually makes use of that possibility as if she had a braille text on paper. For her text production she uses the advantages of indentations and paragraphs. Such text structures are rarely used in paper braille production as their obvious advantages are completely destroyed by the paramount disadvantage of blowing up the paper need, a problem that doesn't exist for electronic paper. A 10-year-old child usually is flexible enough in her or his writing behaviour to adopt the advantages of text-structuring. This was in fact the case with our student who makes use of it in a very natural way.

Several specific tabulator functions offer help for travelling through a text document. Additional features allow the student to change the window position relative to the actual one as well as to jump to a specific position; internally, the lines are numbered and one can get information on the window position any time. As the line display is even shorter than a common text line, one function offers the window to be moved across the line in steps of the window length; this is especially helpful when the right side of a line has to be inspected in a quick look or when a table has to be scanned. Another mode supports continuous fast reading. Hereby, the first window position is moved forward to the first position of that word which was not completely covered in the position before. Of course, continuous reading with a small line display is more complicated than braille reading on a whole page is. However, the student is able to read in this mode nearly as fast as the average of her sighted classmates, and special practicing could improve her reading speed significantly.

Fast and direct text exchange

It proved especially useful that the position of the braille creen is marked on the monitor screen by inverting the respective 20 characters. The sighted teacher can follow the actions of the blind student, and the student can read text or a formula which is typed in by the teacher on the computer keyboard. Thus the system works as blackboard and exercise-book, and the teacher easily gets the necessary feedback. In certain cases, e.g. home work or tests, the teacher will want the student's work printed out on paper. The daily practice shows that it was a wise decision to place a printer directly beside the computer so that, whenever necessary, the student can produce a hardcopy without any help simply by choosing the print command after finishing her work. The text is then printed out immediately and the printed pages are detached by the student herself. The teachers get the work without being involved in the techniques of the procedure. So the only difference between her and her sighted classmates' work is that it is not handwritten but printed.

Writing and manipulating text

For the writing process the student can choose between computer and braille keyboard. Our student prefers the latter one because its arrangement on the VersaBraille is very handy for control reading purposes. It is much easier to replace the hands back to the six large braille keys than to find the exact position on a large and unstructured computer keyboard with some 50 keys. The student actually writes much faster than her classmates do, and her writing speed compensates sufficiently for the greater amount of time she needs as a blind person to get complete overviews of the texts.

The system offers functions that allow the user to manipulate the information on the electronic paper as if it were written on 'real' paper. That means, the user is provided with the functions of pen and rubber. Furthermore, it is easy to transfer or copy pieces of text to other positions or to insert new ones as if cutting the paper and pasting the pieces together in a different order. The resulting text is immediately available in the new form which is exactly the same in the tactual representation as in the version on the monitor and on the print output. The interaction between user and computer is realized by the pointing-technique: the user moves the window to the beginning and end of that part of the text which he wants to define; in the same way, the computer can lead the user to specified areas by window positioning. That pointing-technique is the basis of this easy-to-learn and powerful interactive system. Functions are either chosen from pop-up menus or by entering some characters through one of the keyboards. In her different stages of experience this combination of a menu-oriented and command-oriented interaction provided the student with the appropriate working-mode.

Text preparation

The person who prepares texts for the student can, of course, also make use of the advantages of the BrailleButler system. In an ideal mainstreaming situation, a school assistant should be available for one or two hours per school day to enter exercises and texts for written assignments and tests. In our case this work is done by the student's mother. However, thanks to the convenience of the procedure, the time load so far is limited to less than five hours a week and nearly all of that time is used for the transcription of textbooks, charts, pictures etc. If not dictated, exercises for tests are entered in advance by the respective teachers.

Special features in different subjects

Due to the system's support the student can do dictations, compositions and foreign language translations in the same time as her classmates. As a writing and reading instrument the BrailleButler is also used for mathematics (not, however, as an automatic calculating system). There are no serious representation problems with arithmetic formulas as all numbers and basic operation symbols have a unique braille equivalent. For symbols not contained in this code as well as for fractions, substitute representations had to be agreed upon. The notation is guided along the common representation in programming languages (FORTRAN notation). Symbols whithout representation in the ASCII-code are represented as a combination of existing signs. The chosen combinations allow immediate interpretation by the sighted persons involved. That procedure has never caused any problems. We are convinced that we can proceed in this way also in the upper grades. Working out mathematical text often requires a lot of cross checking. Such reference checks are e.g. necessary for written multiplication and division or for manipulations which need intermediate calculations. For that purpose the student makes ample use of the system functions that support the required travels across the electronic page.

In geometry, during the first two years, the student produced drawings like her classmates, on special raised-line drawing paper. This procedure is very complicated and required some extra time for the student, a circumstance which led us to the design of a special geometry system, GEOTAC (4), for mainstreaming students. GEOTAC is based on the same principles as the BrailleButler system. The drawing is realized on an electronic page, a sighted person can look through the monitor while the blind person gets access through a vibro-tactile screen, the output device of the Optacon (5), a widely used reading aid for the blind. The Optacon is connected to the Apple by a special interface (6) such that the 24 by 6 pins of its tactile display reproduce the pattern of a respective window on the CRT-screen as a vibrating pattern. Moving the window across the monitor screen causes the respective vibrating pattern to move across the fingertip which is placed on the display. At home, GEOTAC now supports the blind student in her production of geometric drawings which can be printed out for the teacher. It provides software realisations of all the functions that can be carried out by pen, ruler, compasses, protractor and rubber. With these aids drawings can be produced, inspected and measured. Objects are drawn either by pointing (e.g. to two different positions for drawing a line) or by specifying coordinates, angles and distances. For overviews and orientation specific extracting and zooming functions are provided. Up to now our experience is very encouraging, GEOTAC proves very comfortable, but good working skills need a lot of practice. The only drawback when using the system in class is the intensive tone of the vibrating display which we intend to reduce before using it in school.

CONCLUSION

Our four-year experience has shown that for mainstreaming blind students the use of the microcomputer system BrailleButler solves all text communication problems. This is due to the following basic principles: texts are strictly held electronically to guarantee unproblematic text communication between teacher and student; the student is provided with easy and comfortable reading and writing functions due to the use of innovative computer interaction techniques for the blind; the necessary equipment is available at school and at home; and the student can use and handle all the equipment involved without any help. Reports from other students who have meanwhile based their mainstreaming efforts on the same system underline the success of our method.

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A SURVEY OF POTENTIAL USERS: DESIGN/OPERATIONAL FEATURES FOR A READING AID FOR THE VISUALLY IMPAIRED POPULATION

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ABSTRACT

A national survey of blind and severely visually impaired persons points to a number of design and operational feature considerations for an optical character recognition computerized reading aid. Respondents were interviewed by telephone to determine demographic information; current reading methods; potential usage of a reading machine; types of reading materials and priorities of reading needs that should be addressed by machine; design characteristics considered important by the consumer; resources available for obtaining such equipment; and cost, weight, and training considerations. The survey polled 135 potential users of this type of reading aid who are unable to read print by any means of visual enhancement. Those surveyed included individuals contacted through the Veterans Administration, agencies for the blind, university disabled students programs, and secondary schools.

INTRODUCTION AND BACKGROUND

An assessment of reading needs and current use of reading technology by potential consumers was developed as a telephone administered questionnaire, as part of a project to design a portable optical character reading aid for the blind (1). Of the legally blind population, the majority are able to read print with visual enhancement such as magnification. This survey focused on the 25 percent or less who cannot read print by visual means (2).

Although effective in some respects, the two major reading devices available both have severe limitations. The Optacon is an analog device capable of reproducing a tactile image of print or whatever image is scanned. It requires the user learn to recognize the print alphabet with all the variations of type style in a moving tactile form. Considerable training, in terms of days or weeks is necessary to learn to recognize print, track print lines, and develop a speed usually significantly slower than visual reading. The Optacon's advantages are portability, and flexibility. While seldom used to read novels, many blind individuals find it useful to scan and identify documents, as well as read short texts. The second device, the Kurzweil Reading Machine (KRM), although large and immovable, has automatic scan capabilities, uses an optical recognition system to capture the printed document in ASCII format, and outputs the result in synthetic speech. Easier to learn to use than the Optacon, it is unable to read poor quality print, and its cost (recently reduced) is beyond the range of most individuals at $19,000.

Several of these drawbacks have been recognized and form the basis of improvements in the design of the reading machine in this project. It was hypothesized that a portable, relatively inexpensive (under $5000), computer based reading machine, with text search and retrieval capabilities, voice output, and a hand held camera would be a solution to the needs of blind persons to read print. The results of this survey while supporting some of the original design outlined, provide valuable information suggesting directions to take in the development of this reading aid.

METHODS

After identifying relevant areas of interest, a 43 item questionnaire was constructed to obtain descriptive information regarding the subjects background, the need for information processing, the methods of reading and types of print material with the highest priority to be read, the current usage of technology in reading, interest and need for a computer-based reading aid, ratings of features for the proposed reading machine, the ability to purchase equipment, acceptable cost, and type of training preferred. Pilot interviews were tested with fifteen subjects and the questionnaire was modified in the final version to be completed in under thirty minutes.

Realizing a random sample of blind individuals is impossible to obtain, an attempt was made to reach individuals with differing backgrounds from a variety of sources. Because the survey focused on technology, those people already exposed to technology tended to be most responsive. For this reason, a special effort was made to locate subjects inexperienced with technology. These efforts resulted one hundred thirty-five (135) volunteer participants who were unable to read print. (An additional group of severely impaired print readers will be discussed in another report.)

Interviews were completed over a period of several months by three interviewers. Training was given to maintain consistency in the interpretation of answers. A reliability study demonstrated consistent scoring from one interviewer to the next.

RESULTS

Description of survey sample

Slightly more than half of the subjects were referred by private agencies serving the blind. A small number (3.7%) were referred by educational institutions. The remainder (40%) of the sample came from veteran sources. The geographic distribution covered thirty-three states, with the highest number from California (27%).

Ranging in age between 17 and 83, two thirds of those contacted have been able to read print in the past. Approximately one third of the sample is female, due to the high proportion of male veterans surveyed. Trauma is the most prevalent cause of blindness in the survey (26%). Surprising at first, this high figure is probably due to the elimination from the study of the majority of visually impaired individuals (and most age related causes) who are able to continue to read print. The most significant of the other causes of blindness are retinopathy of prematurity (19%), prenatal conditions and rubella (10%), and diabetic retinopathy (9%).

Slightly more than half of the sample are currently employed. Almost one third have retired. One third indicated satisfaction with their employment status, whether employed or unemployed. For the majority (84%) visual impairment led to a change in occupation. Education ranged from elementary school to graduate degrees. Seventy-five percent of the sample have at least some college education.

Patterns of reading

The overwhelming majority (98%) of the respondents use audio methods such as cassette tapes, talking books and radio broadcasting services to obtain information. Almost the same number (96%) use readers, while slightly less (87%) use braille. Forty-seven percent, almost one-half of those surveyed listed technological equipment as a method of reading. While most (81%) ranked audio as first or second in importance for reading, a much smaller group (21%) ranked technology as first or second.

The relative importance and current methods of reading various types of print materials was asked of the subjects. The first two columns in Table 2 give the ranking of importance of these print categories by the entire sample, as well as, the experienced sub-group. One third expressed satisfaction with their current reading methods. The majority (85%) are interested in reading material not currently read, while forty percent need to read material with technical or math symbols.

Problems encountered in reading

Some significant problems when accessing print information were identified by the survey. As illustrated in figure 2, the primary difficulty reported is inefficiency or excessive time required to obtain information. One person commented that it took two hours more a day to do the same job as a sighted person. Other comments referred to delays in obtaining information when having material taped, or scheduling readers. Although some indexing is possible, tapes are difficult to scan for information. Locating previously read information was identified as the second most prevalent problem. Privacy when using sighted readers, understanding printed page formats and accessing equipment for reading, while still significant difficulties were reported less often.

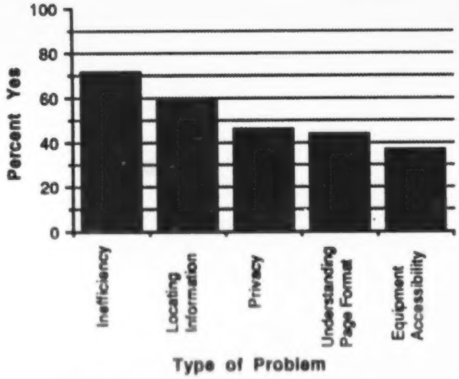

Figure 1.
Non-print users' ratings of specific variables as problems in utilizing print materials (N=135).

Use of technology

A high proportion (53%) of those surveyed have more than on
year of experience using technological reading aids and adapte
computers for the visually impaired. Almost all (90%) have ha
some exposure to technology. The most common equipment i
use is the Optacon and the Kurzweil Reading Machine. A ver
few use optical character recognition (OCR) type devices wit
computers. While this equipment is commercially availabl
adaptation for use by the visually impaired is just beginning

Table 1.
Importance rating and use of technology to read various print materials.

Print Material	Importance (%)[1] Entire Sample (N=135)	Experienced[3] Users (N=71)	Optacon Usage (%)[2] Optacon Users (N=53)	Experienced Users (N=71)	KRM Usage (%)[2] KRM Users (N=40)	Experienced Users (N=71)
Typewritten papers	81.0	86.1	47.2	35.2	52.5	29.6
Bills/Bank statements	77.1	81.9	43.4	32.4	0.0	0.0
Reference books	70.9	70.8	18.9	14.1	5.0	2.8
Copies (xerographic)	70.9	77.8	37.7	28.2	37.5	21.1
Forms/Spreadsheets	68.7	69.5	17.0	12.7	10.0	5.6
Textbooks	68.6	81.9	11.3	8.5	40.0	22.5
Books	67.2	70.9	15.1	11.3	42.5	23.9
Mail/Brochures/Ads	59.7	55.5	45.3	33.8	10.0	5.6
Magazines	58.9	52.8	17.0	12.7	22.5	12.7
Newspapers	52.2	41.7	3.8	2.8	0.0	0.0
Dot matrix	47.3	52.7	17.0	12.7	10.0	5.6
Schedules	42.5	38.9	3.8	2.8	2.5	1.4

[1] Represents ratings of Important or Very Important for the utilization of the listed print materials.

[2] Represents reported usage of the Optacon or Kurzweil Reading Machine (KRM) to read at least a portion of the listed print materials encountered during normal activities.

[3] Users who have reported one year or more experience with technological reading and/or information processing equipment.

SURVEY OF USERS

Thirty of fifty-three Optacon users with one month or more experience reported using the device to read at least one of the print categories listed in Table 1. Twenty-seven of the forty KRM users, report using the equipment to read print information. Table 1 itemizes the actual usage of the KRM and Optacon to read print in various categories. As noted in the bold-faced sections of Table 1, bills/bank statements and miscellaneous mail is significantly read more often using the Optacon, while books and textbooks (distinguished by graphic material, tables, etc.) are read more often with the KRM.

User preferred characteristics

Table 2 outlines the results when subjects were asked the importance rating of a number of possible features of a reading machine. Of note are the bold-faced items in Table 2: hand scanning and automatic page turning were ranked lower than other items. Braille, while still given importance ranked much below synthetic speech as a preferred output mode.

A majority of 69 percent would consider a maximum of twenty pounds transportable, although not necessarily easily portable. Portability is considered high in importance by most of the sample. The equipment cost respondents would be willing or able to pay ranged from none (12%) to $15,000 (one subject). Sixty percent stated $2000 or less. Almost half would choose training with an instructor, another third would like both self-training and instructor options, while the remainder would prefer self-training.

DISCUSSION AND CONCLUSIONS

A clear difference between the hypothesized features and those desired by potential users appears when hand scanning was considered. Automatic page scanning was definitely preferred. Comments that the Optacon is slow to use, and that hand tracking is difficult were made throughout the survey. Tracking issues have been studied (3) and support reconsideration of hand scanning as a primary option for a reading machine. This option may, however, be useful for some tasks, as current Optacon usage demonstrates.

Two areas of further investigation indicated by the study results are: 1) An extension of the survey to expand the information obtained from the experienced user group (4), and 2) The benefits of this type of reading machine for visually impaired print readers those who read print with difficulty and extreme magnification.

The problems encountered by blind individuals in managing print information, the importance of being able to read most print materials, the interest in using such a reading machine and the limitations of current technology conclusively demonstrate the need for an improved reading machine. In doing so, the designer must meet the challenge of reading the range of print types required, handle changes in type style within short texts, columnar items, varied formats, and technical symbols, keep cost low, provide automatic scanning along with portability (bulkier and more costly than handscanning) to produce a reading machine that would meet the needs suggested by this sample of the visually impaired population.

Table 2.
Expert non-print users ratings of the importance of characteristics in a reading machine (N=71).

Characteristic	Importance Rating	
	Not Very/Slightly Important	Important/ Very Important
Stand Alone Capability	7.0	87.4
Spoken Information	4.2	87.3
Computer Compatibility	7.0	85.9
Page Format Recognition	2.8	83.1
Portability	5.6	80.3
Auto Page Scanning	10.0	75.7
Braille Information	16.9	63.4
Hand Scanning	**31.4**	**47.1**
Auto Page Turning	**47.2**	**30.0**

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ELECTRONIC BRAILLE NOTE TAKERS FOR THE BLIND

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ABSTRACT

The concept of creating a highly portable electronic note-taking device using a small braille keyboard and semiconductor storage elements has been taken up by researchers in both the United States and Europe. This paper discusses the merits, applications, and possible variations of this concept, with particular reference to experience gained with the Smith-Kettlewell Note-a-Braille.

INTRODUCTION

The time-honored use of slate and stylus is convenient and adaptable enough to form the principal note-taking method for braille users. Pocket-size versions of the slate are available in many variations, for use with either full-sized paper or smaller note cards. Few braille users doubt the advantages of written notes vis-pa-vis tape recordings, which cannot match braille for random accessibility and selectivity of information, let alone the literacy which braille affords.

However, this traditional note-taking method has its limitations, especially when compared to the alternatives available to the sighted.

a. The slate is slow (requiring an average of 3 sequential "strokes" per character. Even making full use of contractions cannot fully compensate for this.

b. The "crunching" noise generated by the stylus and the paper can be bothersome in many situations such as meetings and lectures.

c. The inherently bulky nature of braille text can to some extent negate the portability advantage of pocket-sized slates.

The advent of low-cost computer memory chips has afforded an opportunity to improve on this situation in at least some respects, through the recent simultaneous development in both North America and Europe of portable electronic information storage devices with braille keyboards. These devices are intended primarily or solely as data entry and storage devices, the intention being that the user can later take the unit home and download the text to his computer for word processing and/or output in the desired form. The remainder of this paper is devoted to a detailed description and analysis of such devices, drawing on our experience with the Smith-Kettlewell Note-a-Braille, but referring also to the other similar systems which have been developed elsewhere with different emphases and features.

THE SMITH-KETTLEWELL NOTE-A-BRAILLE

The concept of the Smith-Kettlewell Note-a-Braille (Figure 1) was to provide the blind user with a basic, low-cost, ultra-portable note taker. The system uses a 9-key keyboard (including the space bar and 2 extra keys for upper case designation and control characters). A soft audible click tells the user that each "chord" has been properly entered. The entered data is stored directly in 8 kilobytes of CMOS RAM--sufficient to store the equivalent of at least 6 full-sized pages of braille. Via an internal EPROM with a stored look-up table, the data is made available in standard ASCII code both in real time as it is keyed in (allowing use of the Note-a-Braille as a data entry device) and later in the downloading mode as a continuous stream. This output is wired in a standard parallel interface configuration, for direct transfer of text to a printer, braille embosser, or computer. A separate commercially available parallel-to-serial converter module can be used if needed. Once downloaded into a computer, the text can be processed as desired for eventual output in print, speech, or braille.

The design has been made available in the public domain and the cost of parts is approximately $80. In commercial production the target selling price will be $250.

Possible future add-on modules may include speech or braille output and means for editing the data within the note taker itself. However, the basic design philosophy was to provide the simplest possible portable note taker and allow the user to accomplish more sophisticated review and editing functions on his home or business computer. Other possible developments of the Note-a-Braille may include further reductions in physical size and incorporation of greater amounts of memory.

OTHER EXAMPLES

A similar basic electronic braille note taker, the Insight Pocket Brailler, has been developed in the United Kingdom. In this case, a basic 7-key (i.e., without separate keys for upper case and control) keyboard layout is used with an 8000-character memory. A serial interface and a paper tape embosser are available as external options. Selling price for the basic Pocket Brailler is approximately $370.

Simultaneously with the development of the Note-a-Braille, researchers at the Kentucky Bureau for the Blind conceived a device known as the "PocketBraille" as a variant of their Porta-Braille system. The design philosophy in this case was to incorporate the relatively elaborate features for reviewing and editing stored text which are included in the PortaBraille. The PortaBraille's braille display is, however, replaced by a built-in speech synthesizer. A serial interface and memory for up to approximately 60,000 characters are also incorporated. The resulting device will be more bulky and expensive than the "bare-bones approach" would allow (costng $600 or more when manufactured commercially) but will provide the enhanced capability needed by some users. As in the case of the Note-a-Braille, the design has been made available to the public and the total cost of parts is approximately $150-$200.

DISCUSSION

Experience with the Note-a-Braille to date suggests that as a note taker it offers the following advantages over traditional methods:

1. Use of a standard braille keyboard configuration is considerably faster than use of a slate and stylus. Users also appreciate the ability to generate upper case and control characters directly using the two extra keys.
2. Operation is considerably quieter than that of the slate.
3. The device is less bulky than mechanical braillers.
4. By functioning purely as a data entry and storage system, the electronic note taker effectively allows the blind user to take the power of his computer to class or meetings.

Naturally, the electronic note takers described here are more expensive than the braille slate, though not the mechanical brailler.

The further evaluation of these devices in the coming months will reveal the desirability for different classes of users of providing such features as speech synthesis, braille output, larger memories, and editing capabilities--versus the extra cost in size and dollars these imply.

Whatever the outcome of these evaluations, however, we believe that the new class of braille note takers represented by our own version and the others described in the paper will provide major benefits in convenience of note-taking and information handling for many blind individuals, and it is hoped they may even help to enhance the popularity of braille as a medium for blind literacy. Indeed, these devices may give the blind user some advantages over his sighted counterpart, since equivalent devices for the sighted are handicapped by the large size of the standard qwerty keyboard.

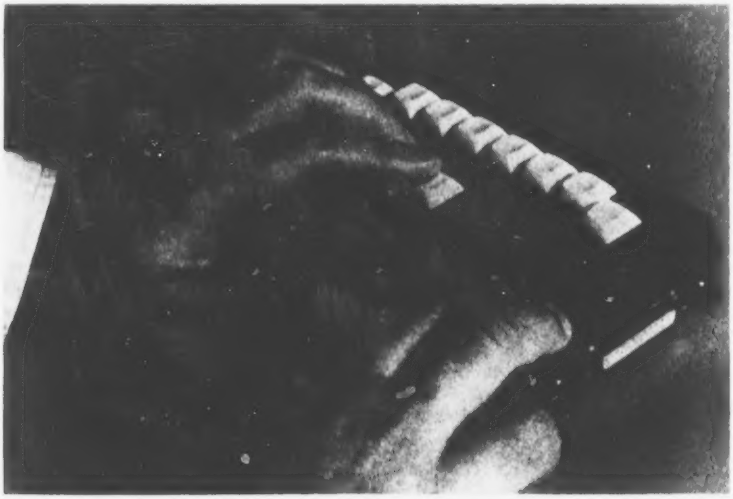

Figure 1. The Smith-Kettlewell Note-a-Braille

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A NEW COMBINATION UNIMANUAL AND BIMANUAL BRAILLE KEYBOARD

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ABSTRACT

An augmentative 9-key braille keyboard is described and demonstrated. In its braille mode, all braille characters can be entered with one stroke by the right, left or both hands. There are two redundant keys to facilitate efficient unimanual use. In its ASCII mode, all ASCII characters are entered with up to two keystrokes by the right, left or both hands. This facilitates its use as a computer-input device for either braille or print text.

The design has been implemented using software on a standard Apple II series keyboard. It is demonstrated from within a powerful, word-processing and utility program system called BEX (Braille-Edit Express). This pace-setting program also supports braille and speech output and a choice of ten screen display modes. After it is fully tested, keyboard design specifications will be written for fabrication of the keyboard in hardware.

INTRODUCTION AND BACKGROUND

"Why must we tie up both hands to use a braille keyboard?" I asked that question when I began using a braille writer 47 years ago. Others asked it too, but little was done. To my knowledge, braille keyboarding skills have never even been rigorously studied. When my teacher told me that on a braille writer, my little fingers could take a vacation, I said, "May I go with them."

I didn't mind using two hands to type on a braille keyboard until I discovered that sighted people could view text and type at the same time. When copying braille piano music, I found it tedious to read and remember the notes long enough to copy them. If only one hand could perform each task, I could move along much faster.

As I grew older, my hand grew large enough to do just that. I could reach all but four large braille characters with one keystroke. It took quite a bit of manual acrobatics which slowed down the process. Even so, it was faster and mentally much easier than going back and forth from page to keyboard every few characters. I didn't have to remember the meanings of symbols - only braille characters, from one to several at a time. I could listen to music or a story while copying and proofing music or technical text. Even those who read braille with one hand can easily proofread technical text such as music with a hand on each copy. I would copy a set of orchestra parts for a teacher in two evenings. My grateful teachers gave me use of a braille typewriter while the others had only braille slates.

Then I found the technique valuable for working with formulas, math problems, foreign words and writing address cards. I could also hold the paper in place with one hand while adding notes in the margins. The benefit is that having one hand for each task permits you to focus more attention on the task at hand and less on recalling as many characters as your memory can hold. When copying or proofing, this technique makes it easier to focus at the character level. When your task is learning, the same technique makes it easier to focus at the symbolic level. Now, computers widen the array of situations where this improved feedback loop would be helpful. We could more efficiently read the output in braille as we type, edit or issue commands.

Over the years, I tried all the options for one-hand entry of braille data I could find. The first was the one-hand Perkins Brailler. For a large, limber hand, it proved no better than my method because it required too much hand movement. Three keys are disconnected from the escapement mechanism, so one must either press the other three and/or the spacebar to move the carriage. This reduces the acrobatics but increases the hand movement. I bought the Canadian keys for my Perkins but didn't like them either. Designed for weak hands, they extend the keys at different angles. The force required and the space between some keys is reduced, but the distance of key travel is increased which makes unimanual operation awkward.

Here at the Hines Blind Center in the 1960's, I had two braille students who had the use of only one hand. I got a Suggestion Award for modifying an L. C. Smith braille writer for them. We disconnected three keys from the escapement mechanism. That worked but proved to be no better than the one-hand Perkins.

Recently, Peter Wung designed but did not build a braille device with a unimanual keyboard. A brief description of it appears in the May, 1986 issue of Technology Update published by the Sensory Aids Foundation of Palo Alto, California. I spoke with Mr. Wung and studied the more detailed description he sent. If his design is expanded to implement use with both hands as well, it should be compared with mine. If it can be implemented on the Apple or another keyboard, I will do so.

Thirty years ago, I conceived of this braille keyboard but haven't had the resources to build it. I tried many times to give the idea away to no avail. Now the design has been implemented.

DESCRIPTION OF THE KEYBOARD

The favorite mode of data entry for many braille users is the braille keyboard. Typically, a braille keyboard has two groups of three oblong keys each, with a spacebar between them. Each key controls one dot of the six-bit (64-character) braille code or braille cell. As presented to the reading finger, the cell is three dots high and two dots wide. Characters are formed by simultaneous depression of required keys. The index fingers control the top dots labeled 1 and 4. The left hand controls the left row labeled dots 1, 2 and 3, and so on.

The "Lauer Keyboard" will have eight long keys equidistant from each other with no space between dots 1 and 4. The spacebar is about four inches long. To the left of Dot 3 is an additional Dot 6. To the right of Dot 6 is another Dot 3. On the electronic version, shift keys are provided.

When using this keyboard with two hands, which is the current standard mode, the only differences are that the hands are closer together, and the spacebar is more conveniently positioned. To use it with one hand does not require removal of the fingers from the three keys normally depressed with that hand. So for left-hand use, dots 1, 2 and 3 are operated by the index, middle and ring fingers. Dot 6 is controlled by the little finger which hardly needs a long vacation. That leaves the thumb to work dots 4 and 5. Right-handed use requires a juxtaposed strategy. dots 4, 5 and 6 are normally keyed with it. The duplicate Dot 3 is right under the little finger. dots 1 and 2 can be pressed by the thumb. Long keys make this more convenient than would square computer keys. For this application, flat keys may be better than ones with concave centers.

USES OF THE NEW KEYBOARD

For uninterrupted data entry of text by people with undamaged hands, I postulate that unimanual use will be a little slower than bimanual use, though that remains to be tested after extensive unimanual practice. Even if such is the case, unimanual use would be more efficient for many tasks because of its improved feedback loop. When symbols, as opposed to literary texts, are copied from braille text, I find it much easier to work with one hand always on the page.

Transcribing from tape recordings is often done without benefit of foot controls. The common task of transcribing addresses and phone numbers would be facilitated if one hand could perform each of the component tasks. Refreshable braille displays such as the VersaBraille are often used to read output from their own keyboards or from computers. Interaction would be more efficient if the user had the option of using one hand for input and the other for output.

Programming, mathematics and braille music are major applications for this keyboard. Users often want to read braille while typing program lines. They sometimes reach around with one hand on the Qwerty (ordinary computer) keyboard to do it despite the awkwardness of doing so. This proposed keyboard would make such unimanual entry of ASCII characters much more efficient.

Some computer devices in the U.S. and Europe use eight keys for eight-dot braille. In such systems, one dot is used for capitals and the other for control characters. An alternative mode on electronic versions of this keyboard could allow the two lower dots in an eight-dot cell to be controlled by the little fingers instead of assigning those keys to the two redundant dots.

IMPLEMENTATION ON THE APPLE KEYBOARD

The following specifications describe a variation of the above keyboard for use on any Apple IIe or IIc. No additional hardware is needed. The concept is now implemented in BEX (Braille-Edit Express) from Raised Dot Computing, Inc. of Madison, Wisconsin. BEX is a multi-media word processor which can output braille, large print and speech as well as regular print. It can receive input from either the Apple keyboard or an external one, either as Qwerty-style typing or as braille keyboarding. The program supports file transfer in both directions, and has professional-quality braille translators. The translators facilitate data entry in literary (Grade Two), uncontracted (Grade One) or the computer braille code. Its formatting and contextual replace features combine to make this the most powerful and versatile text-handling software in our field.

The current braille keyboard option in the BEX program uses the "home row" keys. With the Caps Lock down, the user "chords" letters F, D, S, J, K and L to control braille dots one through six respectively. (Early versions used the bottom row.) Control characters are obtained either in the normal way or by "chording" the appropriate braille character with the spacebar. Control keys which are Tab, Return, Escape and the arrow keys work normally. All other keys beep if pressed. Upper-case ASCII letters cannot be entered from this braille keyboard mode; the braille code doesn't require it.

The modification made for this project retains these features and adds the following ones. A = Dot 6, semicolon = Dot 3, V = Dot 4, B = Dot 5, N = Dot 2, M = Dot 1. Upper case entry is implemented as a "sticky key" feature by tapping either letter P or Q. One tap shifts only the next letter into upper case. Two taps shift to upper case, and a single tap toggles back to lower case. Most unused keys beep when pressed.

This design facilitates either braille or full ASCII input with either or both hands. It also permits "chording" with the spacebar to enter control characters (commands) with either or both hands.

The design is fully operational; however, two features are being added. One will optionally relieve the thumb from having to depress two keys at once. To implement this, the Open Apple Key will activate dots 4 and 5. The Solid Apple Key will activate dots 1 and 2. The second addition will make the use of speech more efficient in the braille keyboard mode. At the user's option, the braille meanings of non-alphabetic characters will be spoken instead of their ASCII meanings which is now the case. This "talking braille" feature is currently used in PEX when the user wants keystrokes spoken and for making searches and corrections in braille material even when no braille device is connected. In PEX, sighted users can choose to view print characters or their braille dot equivalents.

After testing, the next step is to build and test two hardware models. One would duplicate the Apple-based configuration. The other would implement the earlier description. It will feature eight long braille keys placed close together, a spacebar and shift keys. dots 4 and 5 could be controled by the thumb with the left hand reaching across. Similarly, dots 1 and 2 could be operated by the right thumb. That's awkward with the square keys of a computer keyboard, so we didn't do the 9-key version on the Apple. With the oblong keys of a braille keyboard, it should be convenient. That's why the 9-key version was not implemented first.

This same hardware could also support an alternate mode which would work only with two hands. In this mode, ASCII capitals would be sent when, say the Semicolon Key was pressed with any other combination of keys. The A Key could be used to input control characters. The idea here is to duplicate the eight-dot braille cell and keyboard used in some European instruments, by Vtek of Santa Monica, and in the Note-A-Braille by Smith-Kettlewell of San Francisco. The European keyboards and Vtek's display have it the other way around. Dot 7, to the left of Dot 3 is their capital indicator, and Dot 8 to the right of Dot 6 is for control characters.

THE RESULTS AND THE PROMISE

So far, with myself as the only subject, the results are very encouraging. I find it highly rewarding to be able to enter data in braille or ASCII with my left hand without stretching or moving the hand. The adaptation is pleasingly easy for me, but then I have been wanting this for thirty years while using, what I consider, clumsy and inefficient methods. When I came to the VA as a braille teacher 26 years ago, a secret goal of mine was to implement this keyboard design, so I may have an emotional bias.

The next steps are to write documentation for testers and to solicit test subjects from among the hundreds of PEX users. Then, if indicated, the hardware devices must be implemented and tested. Resources are being solicited for this.

Is this an idea whose time has come? Computers are raising the efficiency of sighted people whose two hands can type while their eyes watch the screen. Braille is a marvelous tool which requires no eyes but a hand to read. If we can use this keyboard to write it efficiently with one hand, we can be much more competitive. Those who must type with one hand will no longer need a special modification. Good braille printers are now more affordable. An improved VersaBraille and other soft copy (refreshable) braille display instruments are on the horizon.

The "Lauer Keyboard" is augmentative, not exclusive. It invites but does not require new skill acquisition. It's use does not impede efficiency with existing braille keyboards. The nine-key version is conceptually simple, but if multiply-handicapped users find the additional keys distracting, those keys will be easy to disconnect. Finally, the cost of designing it into new equipment will be low.

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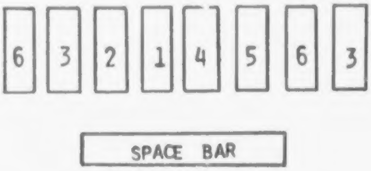
2 • • 5
3 • • 6

BRAILLE CELL



LAUER KEYBOARD

AUDIO AND TACTILE FEEDBACK STRATAGIES FOR TRACKING

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ABSTRACT

The difficulty of the task of tracking a line of type by hand without visual feedback has been a limiting factor in design of hand held reading aids for the visually impaired. Different forms of tactile and audio feedback were compared in 22 subjects performing a straight-line manual tracking task equivalent using a hand held reading device. A simulation of the proposed camera and feedback system was developed using an Macintosh computer, with the mouse representing the camera. Stored text was output by a speech synthesizer when the user guided the mouse accurately. Audio feedback was produced using the Macintosh's free-form wave synthesizer. Pitch, frequency and wave shape were modified corresponding to tracking target zones as an audio map of the text. An Optacon was used to produce four varieties of tactile feedback. 22 subjects: 12 with visual impairment, and 10 with normal vision, tracked the text with audio, tactile and visual feedback. Average accuracy was within the tolerance of the system in almost all completed trials, although subjects gave up on some trials. Scan time was three to four times longer with tactile and audio than with visual feedback.

INTRODUCTION

The goal of this study has been to establish baseline information on feedback and its effect on performance of manual tracking in order to establish design and operational parameters for reading aids for the visually impaired community.

The flexibility of hand-scanning make it particularly useful in intermittant reading tasks such as sorting mail, checking typing, scanning and identifying text for later use. A portable device can be *where* the reader is *when* he or she wants to read, vastly expanding the individual's independence. Portions of text can be selected in any order, which is difficult to do with to tapes. The hand-scan device can provide direct access to bound, or non-standard shaped material which would not easily fit onto the platen of an automatic optical character recognition unit.

BACKGROUND

Experience at Haskins Laboratories in the years following World War II shows that the reading aids of the day failed to meet the real needs of blind users because of unacceptably slow reading rates, long training times, and dependence on specially prepared materials. The development of optical character recognition (OCR) for text capture, and compact and affordable speech synthesis units offer "potential for a revolutionary gain in reading speed and for access to ordinary books" (2).

This potential has been realized within the context of the Kurtzweil Reading Machine (KRM), which automatically scans and recognizes text and can output synthesized speech. Limitations of the KRM, however, are its cost and large size, which makes it a fixed location device (6).

The Optacon, a hand scan device that translates text to a vibrotactile image, is extremely portable, and very successful for those who can learn to use it. The difficulty of interpreting the tactile display and the long training period required keep the Optacon from being a general reading machine solution.

In 1982 Moyer evaluated the Hand-Scan Output Reading System HS-1, developed by Telesensory Systems, Inc., the maker of the Optacon. The Hand-ScanI was a hand held OCR unit which used an Optacon camera and tactile display coupled with a speech systhesis output. The system was tested with 121 users, with training periods of 10 to more than 20 hours: 91% discontinued use of the system within two weeks. The most common reasons given for discontinuing use were: 1) the tracking accuracy required, 2) fatigue caused by system use, 3) the specific nature of reading required 4) lack of portability and 5) the fixed location of the system (Mo).

Work is underway at the VA Rehabiliation Research and Development Center in Palo Alto to address the issues raised by the Hand-ScanI (3, 8, 9). This paper covers one aspect of the the work on the tracking accuracy problem: provision of feedback for the tracking task. Another being examined is the development of technology to increase the size of the camera aperature, thus creating a more error-tolerant system (4).

METHODS AND MATERIALS

Subjects

Twenty two subjects: twelve with visual impairment, and ten with normal vision participated in the test. Eight were Optacon users. Fourteen were woman and eight men.

The Simulation

The simulation represented an approximation of many features of the future reading aids user interface. A program for the Macintosh was written in FORTH, which monitored the relative position of the mouse. The mouse's position at the time the trial was started was the point of reference corresponding to the first character of the stored sample text. The mouse is an input device which registers travel in the X and Y directions. When it was tracked in the X direction, characters were "recognized" from the stored text in proportion to the distance traveled. Any excursion in the Y direction was registered within the computer, and feedback was given indicating tracking error up or down.

Synthesized Speech Output

Stored text corresponding to that "read" by tracking was sent to a DEC-Talk speech synthesis unit. The user "read" while the button on the mouse was depressed. Speech was generated when the user released the button . Speech output was provided to one ear through headphones, and when audio feedback was in use, it was presented at the other ear.

Text and Visual Display

All trials were conducted using the same eight line paragraph, from the fourth grade level SRA Reading Program. A dotted line drawn during tracking traced the path of the cursor point. The cursor was shaped to direct attention to the text "coming-up ahead", and to provide a smaller point area to match to the "target".

Audio-Accoustical Shaping

Audio feedback was produced using the Macintosh's internal free-form wave synthesizer. The tracking field was divided into three zones: on target, high and low. Pitch, frequency and wave shape were modified to create a distinct sound quality for each zone.

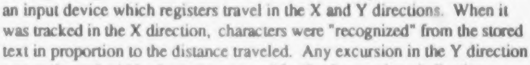

Figure 1. Wave Forms corresponding to different tracking zones

Modes of Tactile Display

The 6 by 24 pin array of the Optacon was driven using the CARA system developed under a previous VA Merit Review grant (3). The display was presented to the hand not tracking, and subjects manipulated the intensity of vibration at will. Four forms of tactile feedback were compared: **image**, in which the portion of the text within the cursor box was displayed much like the conventional Optacon image; **line**, in which 2 x 6 array of vibrotactile pins was displayed to represent position of the tracked "line"; **dot**, in which a square of four pins vibrated higher or lower in the display corresponding to the vertical excursion of the mouse; **Rubber Line**, in which an Arrow or "V"shape was displayed pointing in the direction of needed correction.

Testing Procedures

Subjects were given a period of five to ten minutes to ask questions and get the feel of the system. The components of the simulation were identified, and the function of the mouse explained, but no training, or suggestions were offered. The instructions were to scan the paragraph as quickly and accuarately as possible.

The order in which feedback modes were tested was not fixed. In general, sighted subjects completed ten trials under visual feedback, then completed ten trials each under audio and as many of the tactile modes as time permitted.

During some trials the same line was tracked more than once. In these cases, the time scores were normalized to eight lines. Scan time was measured in 60ths of a second during the button-down tracking cycle only. Tracking error was recorded in pixel units which are equal to 1/72 of an inch. The average, root mean square and maximum error statistics were computed with all values scaled by 1000. The simulated aperature size was 40 pixels in height. Maximum excursions of 10 pixels up or down were tolerated without dropping characters. Therefore, a score of 10000 represents the maximum error for "reading".

RESULTS AND DISCUSSION

As was predicted prior to the study, visual feedback did produce the maximum accuracy and lowest times to scan the paragraph. However, accuracy with audio feedback came in a very close second. In virtually all subjects, the average errors were well within the reading threshold of the system. Maximum errors varied ranged from tolerable to far beyond the point where speech was generated. When these large errors occured they greatly degraded the intelligability of the speech and often left the user scanning a different line than the one started on. (See figure 2).

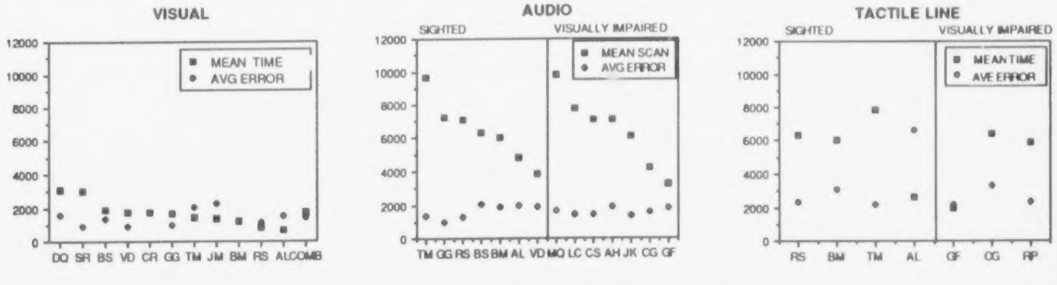

Figure 2. Average scan times and average errors for visual, auditory, and tactile line tracking.

Tracking a single line , finding the line, and mapping the page, retracing the line

The skills involved in tracking a single line: attention to feedback, and accuracy of proprioceptive response, are simpler than those required for the task of orientation on the page. Finding the first character of the line, determining it to be the correct line, and scanning the line are distinct tasks. Different individuals came up with different stratagies for orienting themselves, and maintaining their spatial relationship to the unseen page which were more or less helpful. More study is needed to look at the relationship between the mapping suggested by the feedback design and the user's system for developing an internal model of the tracked page.

Subjective Reactions to Feedback

The similarity of the image mode to the true Optacon display created some conflict for the experienced Optacon users whether to "read" the display itself, or to simply use it for tracking feedback. The dot and line modes were problematic for these users because they departed from the Optacon convention of up and down. Many users could not orient themselves in the dot mode, but two subjects prefered it to the other tactile modes. Frustration was sited by six subjects who attempted but did not complete some or all of the tactile trials.

Most subjects adjusted rapidly to the audio feedback. Only three subjects were unable to track at all on the first try using audio feedback. Six subjects disliked the sound of the audio, although most of these individuals performed well using it.

Speed vs. Accuracy

As would be expected, speed and accuracy varied inversely. Though there is not enough information on learning and training with the system to state unequivocally, it appeared that learning alternated between skills for optimizing accuracy and those for maximizing speed. Fast, innaccurate trials were often followed by more accurate trials which retained some of the improvement in speed gained.

Apperature Size, Ease of Trackability, and Open and Closed Loop Feedback

The experience of HandScan One underscores the importance of the target, or window size on the difficulty of the tracking task (7). The larger the window, *ie* how far one can stray up or down without losing text, the more probable the sucess of the task.

In the present simulation the tracking task is performed with a closed feedback loop in which position is constantly monitored, and corrective movement made, relative to the goal of staying on the line (5). It is believed that there exists a threshold aperature size at which tracking difficulty would decrease dramatically. With sufficient error tolerance, tracking could be performed with an open feedback loop: position would only have to be monitored at the start of the line and then the camera could be swept accross the page without checking its accuracy. In the open loop mode, maximum tracking speeds would be limited by arm trajectory motor control processes rather than information processing. (4, 5).

Rate of reading

Because scan time was recorded only during actual "reading" (scanning with the mouse button down), and not during retracing and searching, scan time scores cannot be reliably translated into reading rates in words per minute. As a first approximation, a scan time of 5000 sixtieths of a second means the rate of scanning*over a single line* was appromately 58 words per minute. A scan time of 2500 sixtieths of a second would correspond with 116 words per minute and a time of 1000 with 232 words per minute. Retracing and searching for the next line take *at least* as long as scanning so a first approximation of the rate would be half or less of the numbers listed. In many cases retracing and finding the beginning of the next line was more difficult than scanning.

Scanning stratagies
Most users scanned one entire line before releasing the button and listening to the text, but search stratagies such as scanning a single word at the beginning of a line to identify it were possible, as was backing up and re-reading a part of a line.

Learning
It was beyond the scope of this study to look seriously at learning. No training was given, and small numbers (5 to 10) of trials completed for each feedback mode. Scores for both accuracy and scan time appeared level out within 100 trials in the visual mode. Larger trial numbers for the other tracking modes have not been carried out, but two areas of interest are 1) What kind of peak and average performance could be attained after much longer periods of practice and 2) whether training would be more effective compressed into a short, intense period, or delivered at spaced intervals.

Fatigue and Frustration
While no objective measure of fatigue was made, subjective comments from users suggest that fatigue and frustration are significant factors particularly in the tactile modes, though also experienced in audio and visual tracking.

Limitations of the Simulation
The mouse registers movement only when a ball in its undercarriage rolls in contact with the table surface. Dust occasionally halted the ball, and there were not absolute limits to going "off the page" physically, although the computer did not register excursions beyond the 512 by 330 pixel array of the screen window.

Design and User Interface Issues in the Simulation
It is important to remember how many system design features had to be approximated in this simulation. The actual camera will in all probability be easier to use than its mouse representation. The movement of the camera across the text would be absolute rather than relative, and cues such as the edge of the page could be felt. A greater number of user definable buttons on the camera would allow greater customization of the system in terms of when and how feedback was given.

As text is input to a computer system, the camera unit could also potentially be used as an input device equivalent to a mouse or track-ball for selecting and manipulating text . The usefulness of such a dual-duty device could very well prove to more than the sum of its parts. For sighted users, the mouse has been shown to outperform joystick, step keys and text keys for text selection (1).

Vibrotactile displays such as that in the Optacon are complex and expensive to manufacture. Some version of the dot or line tactile feedback modes which involve relatively few vibrotactile cells, would be a more cost effective design.

CONCLUSIONS

The simulation allowed many design and operational parameters for reading aids to be assayed and iterations of design to be performed performed very rapidly at relatively small expense. It is probable that the present simulation conditions were more severe than the conditions for use of the actual reading system under development. Features to be incorporated in the reading system under development such as "Soft" user interface parameters and modularity of the system components, promise increased functionality. Issues raised in the course of this study will play a role in determining the operational characteristics of the reading system. Important amoung these questions are: 1) what level of reading comprehension can be achieved with such a system, 2) what is the optimum training schedule, 3) what real reading rates can be attained, 4) how should the user interface be reconfigured, and importanly, 5) how can the design of the feedback be improved, made more pleasant, and less fatiguing.

This study had demonstrated that most people can sucessfully operate a hand scanning reading device with visual or auditory feedback, and a significant proportion of people effectively use such a device with tactile feedback. Whether such a device could meet the real needs of potential users is a question which requires further study.

ACKNOWLEDGEMENTS

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Work Environment Visual Characteristics Protocol: Software for Low Vision Rehabilitation

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ABSTRACT

A Work Environment Visual Characteristics Protocol has been developed for low vision rehabilitation. Information collected using the protocol includes job description, illumination characteristics, environmental factors, mobility needs, and flexibility issues. Software has been developed for report generation. Evaluation of use of the Work Environment Visual Characteristics Protocol data in the low vision clinic indicates that its use is associated with greater patient low vision aid comfort, greater low vision aid use, and fewer follow-up visits for training for low vision aid related problems.

INTRODUCTION

With the increasing use of low vision aids by people with visual disabilities, eye care, education, special education, and rehabilitation professionals have become increasingly aware of the need to provide low vision aids which improve the visual functioning of the low vision individual in the environment in which the individual lives, works, and plays. Environmental assessments are recommended by eye care professionals as a part of the low vision examination to ensure that environmental demands are accounted for in the low vision rehabilitation plan. Because no systematic procedure of environmental assessment existed, the Work Environment Visual Characteristics Protocol was developed at the Mississippi State University Rehabilitation Research and Training Center on Blindness and Low Vision (MSU-RRTC).

Previous work at the MSU-RRTC indicates that assessment of the visual characteristics of the work environment contributes to improving the provision of low vision aids and job modifications, and enhances the employability of people with visual disabilities by increasing work performance rates and visual functioning comfort levels on the job. The Work Environment Visual Characteristics Protocol is an extension of this work, and it serves as a work environment visual characteristics assessment technique.

Information from the assessment using the Work Environment Visual Characteristics Protocol may be used in a number of ways. These ways include use of the information by:

(a) eye care specialists in the prescription of low vision aids for the performance of work tasks,

(b) rehabilitation teachers in training low vision people in responding to visual cues critical to job performance,

(c) rehabilitation engineers to identify the visual characteristics of the visually impaired worker's job, and

(d) rehabilitation counselors and job placement specialists in identifying for employers and the visually impaired worker those job elements which might require job modification.

METHODOLOGY

1. A draft version of the Work Environment Visual Characteristics Protocol was submitted to a panel of low vision rehabilitation experts. The Work Environment Visual Characteristics Protocol was revised following the input of the panel.

2. From a pool of patients referred to the Low Vision Clinic at the University of Mississippi Medical Center, thirty subjects were assigned randomly to Experimental and Control groups. The job tasks required by the employment position held by each subject were analyzed, and on-the-job vision comfort level was assessed. For the Experimental group, the Low Vision Rehabilitation Team reviewed the results of the Work Environment Visual Characteristics Protocol prior to the low vision examination (prescription, fitting, and instruction). The Control group received the same range of services as the Experimental group; however, the Low Vision Rehabilitation Team did not have the Work Environment Visual Characteristics information for this group.

3. Dependent measures included low vision aids examination time (length of examination), number of low vision aids prescribed, fatigue expressed by the subject during the low vision aids examination, number of follow-up visits, subject low vision aid use comfort level on the job, and subject use of low vision aids on the job.

4. Six months after the initial low vision aids examination, information from the Control group's Work Environment Visual Characteristics Protocol was presented to the low vision rehabilitation team for reconsideration. Follow-ups were made where indicated.

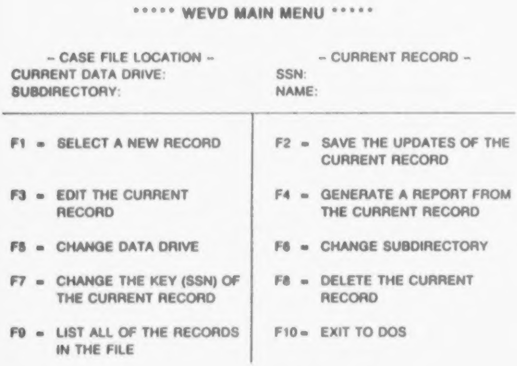
RESULTS

1. Work Environment Visual Characteristics Protocol. The Work Environment Visual Characteristics Protocol was developed. The protocol provides for the assessment of the jobs performed by the person with the visual disability in terms of action, purpose, time present at activity, footcandles observed, and IES illuminance category observed. Vision

requirements such as near vision, midrange vision, far vision, depth perception, shifts in working distance, color vision, field vision, speed and/or accuracy, eye-hand, eyeOfoot, and eye-hand-foot coordination are assessed. Lighting types, levels, and dimensions are assessed. Characteristics of visual displays are also assessed. Environmental factors such as factors surrounding the visual display, mobility requirements of the workplace, and flexibility of the workplace are included in the protocol.

2. Work Environment Visual Characteristics Protocol Software. The Work Environment Visual Characteristics Protocol (version 1.0) program is designed to run on an IBM-PC with 128K bytes of memory and an Epson FX-80, Epson LQ-1500, IBM Quietwriter or compatible printer connected to the line printer port 1. The software is user friendly. It is compatible with large print, voice output, and braille output software. The output from the program includes a report generated for the Low Vision Rehabilitation Team. The report information includes calculation of horizontal and vertical viewing angles, assessment of illumination conditions, opportunities for job modifications, and viewing distance measurements.

The program Main Menu is shown below:



```
                 ***** WEVD MAIN MENU *****

   - CASE FILE LOCATION -            - CURRENT RECORD -
CURRENT DATA DRIVE:              SSN:
SUBDIRECTORY:                    NAME:
-----------------------------------------------------------
F1 = SELECT A NEW RECORD       | F2 = SAVE THE UPDATES OF THE
                               |      CURRENT RECORD
F3 = EDIT THE CURRENT          | F4 = GENERATE A REPORT FROM
     RECORD                    |      THE CURRENT RECORD
F5 = CHANGE DATA DRIVE         | F6 = CHANGE SUBDIRECTORY
F7 = CHANGE THE KEY (SSN) OF   | F8 = DELETE THE CURRENT
     THE CURRENT RECORD        |      RECORD
F9 = LIST ALL OF THE RECORDS   | F10= EXIT TO DOS
     IN THE FILE               |
```

3. Work Environment Visual Characteristics Evaluation Results. The Experimental group was found to report greater frequency of use of their low vision aids on the job and higher levels of comfort using the low vision aids on the job than the Control group. The Experimental group was found to need significantly fewer follow-up visits to the low vision clinic for low vision aid related problems than the Control group. No significant between group differences were found for the other dependent measures.

SPONSOR

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Opinions expressed in this document do not necessarily represent those of the National Institute on Disability and Rehabilitation Research.

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SOLDERING WITH MODERN TECHNIQUES AND MATERIALS

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ABSTRACT

In collaboration with three electronics technicians (readers of the Smith-Kettlewell Technical File), new tools for soldering have been developed. Two styles of solder guides, each with their own advantages and disadvantages, are described. A new soldering iron is also described; this uses parts from a commercially available battery-operated iron.

INTRODUCTION

Traditionally for the blind technician, the procedure for soldering has been seen as a matter of modified technique. A system of landmarks had to be constructed for each and every connection. The eventual melting of solder told the technician that the target had been found, but, at best, this was belated feedback.

Until recently, special soldering tools would have to have been restricted to certain jobs; the variety of connection points and physical arrangements of earlier wiring schemes made generalized jigs and fixtures impractical. Now, however, there is a standard of lead spacing (1/10 inch between centers) and a prevalent tendency for manufacturers to make components with circuit boards in mind. Now that connection points are similar in size and shape, an appropriate guide or soldering iron has universal application.

SOLDER GUIDES

Two "solder guides" (probes that carry solder to the work pieces, as well as providing a guide for placement of the soldering iron) have been extensively tested at Smith-Kettlewell. One, invented by a Japanese reader of the Smith-Kettlewell Technical File and refined in our laboratory, is a piece of so-called "hypodermic tubing"--stainless steel tubing through which the solder is passed. The other, invented by a British reader of the Technical File, is merely a darning needle fitted with a wooden handle.

Japanese Tubular Solder Guide

The Japanese tubular guide (Figure 1) uses thin-walled stainless steel tubing whose outer diameter is 1.83mm and whose inner diameter is 1.37mm. (Standard sizes of solder range from 0.7mm to 0.9mm.) Having an overall length of 100mm, a shaft collar with a setscrew is secured at the tube's midpoint.

In operation, the tube is loaded with solder and held at an angle with its bottom end resting on the work. The user supports the upper half of the tube--holding the solder between thumb and forefinger--cradling the tubing above the collar between smaller fingers. The lower half of the tube is then found with the iron, after which the iron is drawn back and slid down the tube to the work pieces. At this point, forward pressure is put on the solder; when the work pieces are hot enough, melting of the solder will allow a length to be fed forward through the tube (5mm or so, depending on the size of the connection).

British Solder Guide

With the British guide (Figure 2), two or three turns of solder are coiled around a darning needle (whose blunt end is tightly fitted into a small piece of wooden doweling). Then, with the point of the darning needle resting on the work pieces, the coils of solder are slid down to rest on the work. The user supports the guide by holding the wooden handle; the iron is brought in contact with the needle, whereupon it is slid down to meet the solder and the work.

The success of the British guide can largely be ascribed to the small size of modern connection arrangements. The fact that the iron contacts the solder first means that a portion of solder will take to the iron and not to the work. Furthermore, without a surplus of solder present, all of the flux would be used in cleaning the iron's tip, and no alloying would be assured between work pieces. Because the connections being soldered are small enough to need very little fresh solder and flux, this system works quite reliably.

Figure 1. Japanese Tubular Solder Guide

A length of stainless steel tubing shrouds the solder, both protecting the solder from the iron and providing a guide for bringing the tip of a hot soldering iron to the work. The shaft collar at the midpoint keeps the user's fingers from sliding down the tube, thus assuring a 50mm length to be found with the iron.

Figure 2. British Solder Guide

A darning needle of any size is fitted with a wooden handle. With the point resting on the work, a small coil of solder awaits arrival of the iron.

Comparisons
The Japanese tubular guide has the advantage that solder is applied primarily to the work pieces and not wasted in cleaning the tip of the iron. It has the disadvantage of clogging frequently; the flux within the solder acts like a "hot glue" which can freeze the solder in place (unless the user keeps the solder moving through the tube after the job is done). While the British guide cannot clog, it cannot dependably be used where an abundance of solder is required; coiling more solder onto the needle may have the result of dropping short lengths off to the side of the needle's point.

The fact that these guides are stainless steel is important. Stainless steel does not alloy with the solder (unless a special flux is used, specifically designed for soldering stainless steel). In not forming an alloy, these guides never get soldered to the work; in addition, heat transfer to these guides is never very good, since there is no "continuity of metals" (on the molecular level) between the iron and the guides. Furthermore, stainless steel is a poor conductor of heat; this is desirable because a good conductor would "sink" heat away from the connection and lead to partial involvement of the work pieces (so-called "cold solder joints").

Both of these guides have the advantage that their cross-sectional area is small, thus minimizing their heat conductivity. The tubing of the Japanese guide is very thin (0.23mm in wall thickness); with the overall diameter being 1.83mm, the conductive cross-section is only 1.16 square millimeters. The darning needle can be any of various sizes; the diameter of its shank is not critical, since heat transfer through the point is minimal.

SOLDERING IRONS

Choosing a Traditional Iron

Whether guides are employed or the older landmarking techniques are used, the main criterion for choosing a soldering iron has been minimizing the distance from the user's fingers to its tip. (Other minor improvements have made some difference; the ready availability of "temperature-controlled" irons has made them slightly safer, but the length of the hot portion is still the overriding consideration.) This length is important, since it bears directly on the technician's accuracy in finding the target.

"Instant-Heat" Irons as an Alternative

An alternative to choosing the traditional "constant-heat" iron is one which can be guided into position while it is cold, then energized when fingers are out of the way and the setup is stable. If the iron is capable of heating up quickly, as well as cooling in time for the next connection, use of guides and adaptive techniques becomes superfluous.

Such soldering irons do exist. Called "cordless irons," they contain a nickel-cadmium battery which, by way of a pushbutton on the handle, heats a soldering tip only when needed. These have two distinct disadvantages: First, the battery makes the handle heavy and unwieldy. Second, the act of pressing the button puts the operator's wrist under enough tension to destabilize the hand.

A Modified Soldering Iron for the Blind

Recently, in collaboration with the Rehabilitation Engineering Center's experimental "Training/Research Program" at Smith-Kettlewell, a newly blinded technician found a tip assembly (intended for use with the Wahl Clipper Corporation's cordless iron) which permits discarding the traditional handle. The Wahl "Tuner Extension Tip" (No. 7556) is much the same as the tip usually provided, except that its leads have been extended by copper tubes--these conductors are then taped to a spacer and packaged in heat-shrinkable tubing. Powering this tip from an external transformer constitutes a special soldering configuration which is ideal for the blind user.

As seen in Figure 3, the insulated portion of the tip's conductors becomes the handle; a cable coming off the pins at the rear connects the tip to a 2.5-volt transformer. Power to the primary winding of the transformer is controlled by a footpedal. Thus, a featherweight soldering iron is created, and its off-on switch no longer presents an ancillary task to the operator's hand.

There are three distinct disadvantages to this type of iron: Obviously, the rate of soldering a sequence of connections is fixed by the cooling and heating time (about one minute being required for cooling, and perhaps seven seconds for heating). Frequent heat cycling is hard on a bond between the metal portion of the tip and a ceramic insulator to which the heating element is mounted; tips frequently break loose and fail when put to heavy duty. The most serious problem is the lack of temperature control; if left on too long, the tip temperature can climb so high as to oxidize and/or carbonize materials of the work.

However, with gentle handling of the tip, failure can be reduced to a level which is economically acceptable (a $7 unit can be made to last for more than one hundred connections). Also, by carefully monitoring melting of the solder--using the solder as a "pyrometer, so to speak--excessive temperatures can usually be avoided.

At our Rehabilitation Engineering Center, development of a temperature-controlling system is under way. When first energized, the tip exhibits a resistance of 0.3 ohms; as it reaches soldering temperature, its resistance climbs to over 0.4 ohms (eventually reaching 0.5 ohms at a condition of severe overheating). By putting the tip's heating element in a Wheatstone bridge, it is hoped that sensing of tip temperature can be done indirectly by noting the resistance of this element.

If a temperature-controlling system can be made with good repeatability, there will be much less danger of overheating work pieces (the fault being ineffective monitoring of the connection's ability to melt the solder). Furthermore, tip life should increase, since occasional overheating and wide temperature excursions are not entirely avoidable.

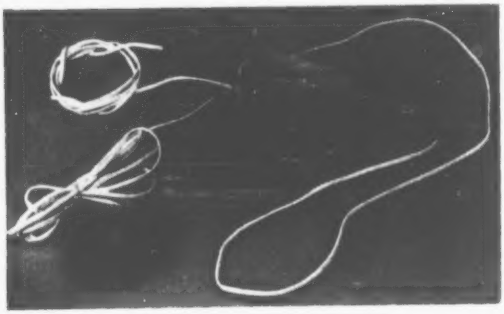

Figure 3. Footpedal-Controlled Modified Soldering Iron

An attachment for the standard Wahl Clipper Corporation's iron, this extension tip is powered by way of a cable from a 2.5V transformer. By putting the footpedal in the primary circuit, no appreciable voltage drop is caused by a long cable on the switch.

CONCLUSION

There was a ten-year period when a commercially available soldering gun served special needs of the blind, but the reduction in size of components eventually rendered this gun obsolete. Now, however, because connection points no longer come in a wide variety of sizes--and, thus, they are of similar heat capacity--a single size of thin solder can be used (of particular importance in the case of the tubular guide). Even for off-board wiring, the terminals encountered all permit the use of these small guides, small solder, and irons of a standard size and power rating.

Acknowledgments
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Special Interest Group 9

Wheeled Mobility and Seating

Chair: Peter Axelson, M.S.M.E.

MOTOR, PERCEPTUAL, AND COGNITIVE FACTORS THAT AFFECT MOBILITY CONTROL

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ABSTRACT

This research project looks at the characteristics of successful and unsuccessful powered wheelchair drivers. A large battery of standardized motor, perceptual, and cognitive skill tests; computer-based tasks: driving simulations and actual driving tests were administered to 57 subjects.

This project has identified several promising predictors of powered mobility control and has produced a computer-based 3 dimensional driving simulation program that is itself predictive of wheelchair driving performance of students who are physically disabled. It would appear quit possible for the 3D driving simulation program to be used as a training tool to help disabled children master driving skills without endangering themselves or others.

INTRODUCTION

Within the context of rehabilitation the term mobility or mobility systems is frequently used to refer to wheelchairs and their technical, ergonomical or aesthetic aspects. This paper looks at another important element of the mobility system, namely the user/operator. While it is essential that mobility devices are dependable, efficient, safe, reliable, adaptable, aesthetically pleasing and ergonomically sound it is at least as important for us to know: (a) what the effects are of the prescription or denial of mobility upon the child's cognitive and social development; (b) what the factors are that positively affect or predict mobility control; and (c) how children can be trained to become proficient wheelchair drivers. This paper will address cognitive and physical factors that affect mobility control and offers implications for training.

BACKGROUND

From 1978 to 1984 three projects were carried out, one in Sweden, one in the USA and one in Canada, that successfully provided powered mobility devices to two-to-five-year-old children (1, 2, 3). All three projects reported positive changes in the children and families. One project (3) found significant gains beyond the developmental norm in academic and social skills and near significant gains in communication. A unanimous conclusion of these three studies was that children as young as 20 months of age could learn to drive a powered mobility device successfully.

Without invalidating this exciting conclusion it is necessary to take into account the following statistics from the HMMC Interfaces Clinic, a facility that provides powered wheelchairs to severely physically disabled clients of ages 2 to 19 years old. Last year this Clinic performed 96 assessment. Out of these 96 assessments only 44 prescriptions for a wheelchair were filled. Hence 52 clients could not take a wheelchair home. These non-prescriptions (denials) were not caused by lack of funds or lack of mobility - or interface - technology, all of which are available in the province of Ontario. Eighty five percent of the denials were based on the fact that the person could not (learn to) operate the powered wheelchair. Given these experiences it becomes even more important to establish what makes a person a successful driver and how driving skills can be trained.

Over the past two years a project was carried out in which predictors of powered mobility driving were investigated. One of its goals was the construction of an assessment protocol for the prescription of powered mobility devices. A second goal was to create a number of computer-based tasks that could be used for assessment or training.

METHODS

Subjects

Fifty-seven (57) subjects were seen in this study; twenty four were able-bodied subjects, and thirty-three were disabled, all were sub-classified in three age groups (i.e. 4-5, 6-7, and 8-9 years-old). Students in the disabled group were further divided into those that had experience with a powered wheelchair (exp.) and those who were inexperienced (inexp.).

	AGE GROUP (AGRP)		
GROUP	4-5 YRS	6-7 YRS	8-9 YRS
able-b.	8	8	8
inexp.	6	6	4
exp.	5	6	6

Table 1: Number of students by GROUP and AGE GROUP.

The disabled students were diagnosed as follows: cerebral palsy (25), spina bifida (5), spinal muscular atrophy (3).

Standardized tests

A large battery of standardized motor, perceptual, and intelligence tests was administered including:

Motor Tests:
Peabody Motor Development Scale (PMDS) collected for disabled students only.

Perceptual Tests:
Motor-Free Visual Perception Test (MVPT); and Ayers Space Visualization Test (ASVT).

Cognitive Tests:
WISC-R or WPPSI Mazes; Raven Coloured Progressive Matrices; Peabody Picture Vocabulary Test (PPVT); WISC-R Picture Completion Subtest (PICOM); WISC-R Picture Arrangement Subtest; Representative Stencil Design Test.

All tests in this battery were administered and scored in the standard way. Standardized tests were chosen rather than tests designed specifically for the purpose of assessing wheelchair driving skills for three reasons. Standard tests provide a link between established psycho-diagnostic tools and driving skills. They are readily available and simple to administer. And several of the tests chosen were shown to be related to auto-mobile driving performance (4).

In addition to this test battery, four computer-based predriving tasks, two computer-simulated driving tasks and two actual driving tasks; wheelchair and remote controlled driving tasks were performed by the students. The six computer-based tasks were developed for this project. Predriving tasks consisted of a targeting task, a tracking task, a test of dynamic perception and a simple maze. All driving tasks (simulated and actual) used the same five courses which were to be traversed in one of two speeds. These courses consisted of (1) straight-away, (2) S curve, (3) sharp (90 degree) left turn, (4) backing up and sharp left turn, and (5) two sharp right turns. For simulations and remotely controlled driving tasks the courses were scaled to the size and speed of the moving object.

A more detailed description of the method and procedures can be found in the proceedings of a recent conference on Childhood Powered Mobility (5).

RESULTS AND DISCUSSION

This and the sections that follow will be concerned with only 21 of the almost 200 variables of the full study. The variables and the skills assessed are:

1. Age: Chronological Age at entry;
2. PPVT: Peabody Pict. Voc Tst / verbal;
3. PICOM: Picture Compl. Test/spatial;
4. MVPT: Motor-Free Vis. Perc./percept.;
5. FM: Fine Motor score of PMDS /motor;
6. GM: Gross Motor score of PMDS /motor;
7 - 11. Variables 2 - 6 above are used in Standardized (ST) and Raw form;
12. WCLow PR: Mean Paddle Read (PR) scores for WC driving at low speed; (The Paddle Read score consists of the number of times the computer recorded a joystick activation while the student was driving each course. This measure correlated highly (r=.95) with course completion time.)
13. WCHigh PR: Mean PR for WC high speed;
14. JP or Jeep: Mean PR of Jeep driving;
15. 2D PR: Mean PR of 2D simulation;
16. 3D PR: Mean PR for 3D simulation;
17 - 21. Mean number of Collisions (CL) for WCLow and High, JP, 2D and 3D.

Students were grouped in two ways. The groupings shown in Table 1 were used for the ANOVAs of cognitive and motor scores. For the regression analysis students were divided into two groups: able-bodied (n=24) and disabled (n=33).

Raw and Standard score differences

In the course of the analysis of the data it was observed that for the disabled students the standardized scores of the cognitive and perceptual tests decreased across age groups. This decrease across age groups did not occur in the able-bodied student group. The test that shows the most dramatic decline in the standard scores across age groups was the Raven Coloured Progressive Matrices Test, a spatial skills test. PICOM and MVPT scores also showed this effect and only the Space Visualization Test did not show a decrease in standard scores for disabled students in the older age groups. Because of this difference in raw and standardized scores both measures were carried in the analyses.

Group comparisons

As can be expected significant differences existed between the able-bodied and disabled students. Differences in all but one of the variables 2 through 4 and 7 through 21 were significant. There were no significant differences between students who are able-bodied and those who are disabled in PR nor in CL scores for WC driving at High speed. This was attributed to the fact that 17 disabled students were experienced powered wheelchair drivers and another eight had experience driving a manual chair. The experienced and inexperienced disabled WC drivers were very similar and differed only in Gross Motor scores and 2D CL scores. The disabled students were therefore treated as one group.

Correlations

As a means of comparing the relationship among motor, cognitive, and perceptual variables on the one hand and WC driving and driving simulations on the other, correlations were computed. Tables 2 and 3 present the ranges of these Pearson pairwise correlations.

	ABLE-BODIED	DISABLED
Perc. Verbal Spatial	.201 to .844	.146 to .776
Perc./ Ver./Sp. with WC	-.083 to -.527	-.003 to -.459
with JP	-.162 to -.749	-.002 to -.159
with 3D	-.163 to -.763	-.076 to -.487
with 2D	-.253 to -.567	-.006 to -.201

Table 2: Pearson correlations among cognitive and driving variables for able-bodied and disabled students.

The negative correlations are caused by the fact that a high PR score corresponds to poorer performance while a high test score indicates better performance. Correlations for the disabled students were lower but displayed the same pattern as those for able-bodied students. The two major differences occurred in tasks, JP and 2D, which were difficult for the disabled students. Both these tasks require the student to assume a decentred (non-egocentric) perspective.

	Raw (Motor)	Stand. (Motor)
r(GM,FM)	-.060 to .370	-.288 to .427
r(GM,Cogn)	-.030 to .274	-.154 to .193
r(FM,Cogn)	.162 to .492	.061 to .518
r(GM,Driv)	-.306 to .152	-.151 to .450
r(FM,Driv)	-.713 to .152	-.785 to .086

Table 3: Pearson correlations for disabled students.

These correlations show that FM scores are correlating most strongly with WC driving and simulation performance, closely followed by the perceptual, spatial, and verbal scores of able-bodied students.

Regression Analyses

Some of the variables that predict the wheelchair driving performance of students in the two groups (disabled and able-bodied) are different and others are shared predictors. The Raw scores predict driving and driving simulation performance better for the disabled students but not for the able-bodied students.

For disabled students WC driving performance was significantly predicted by the spatial skill measure (PICOM) and less strongly by Age and a perceptual skill measure (MVPT). Performance on the 3D simulation task predicted WC driving significantly and was in turn predicted by the verbal test (PPVT). Of the motor measures only the FM scores predicted WC driving significantly, GM scores did not predict performance. The results correspond well with clinical intuition and provide a useful affirmation and potential simplification of the assessment process.

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EVALUATION OF A TEST BATTERY FOR ASSESSMENT OF ELECTRIC WHEELCHAIR DRIVING ABILITY

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Abstract

Little information exists for the clinician to objectively access electric wheelchair driving ability. The objective of this study was to contribute to the development of an assessment protocol in this area. A battery of tests were selected to assess skills which were postulated as being related to electric wheelchair driving. The battery included standardized tests for cognition, perception and physical status, as well as several functional performance measures developed at the Hugh MacMillan Medical Centre (H.M.M.C.). An evaluation of this battery of tests was carried out over a period of 1 1/2 years. The sample population of fifty seven children included both able-bodied and physically disabled youngsters. The results of the evaluation showed several tests were significantly related to electric wheelchair driving ability.

Introduction

Clinicians often provide input regarding the prescription of electric wheelchairs for clients with physical disabilities. They are often the ones who identify their clients' need for mobility, evaluate their abilities, and make appropriate recommendations. However, the current practice of evaluation for an electric wheelchair is very much dependent on the knowledge and experience of the clinicians. In Ontario many clients are referred to the Interfacing Program at H.M.M.C. for evaluation of their potential to drive an electric wheelchair. In order to improve on the quality of care staff at H.M.M.C. sought to establish an objective measure of electric wheelchair driving ability. A battery of tests were selected and a study was initiated to determine the correlation between these tests and the skills required for electric wheelchair driving.

Background Information

Currently the areas a clinician evaluates for electric wheelchair driving potential may include perception, cognition, physical status and functional ability. Of these, perception and cognition may be prerequisite skills for successful driving of an electric wheelchair (eg. depth perception, shape constancy, figure ground, cause and effect of movement, directionality, ability to negotiate obstacles, knowledge of rules of the road). While there are many standardized tests available to clinically assess these areas, there is virtually no work done which correlates these tests specifically to wheelchair driving. A study which may have relevance was contributed by Sivak et al, (1981). They demonstrated significant correlations both with brain-damaged and non brain-damaged adults. Among the tests which significantly correlated were the Picture Completion and Picture Arrangement subtests of the Wechsler Adult Intelligence Scale (Wechsler, 1955) for brain-damaged subjects. The Space Visualization subtest of the Southern California Sensory Integration Test (Ayres, 1962) correlated for non brain-damaged subjects. However, one should take precaution relating their conclusions to wheelchair driving although intuitively car driving and wheelchair driving are similar skills.

Another often assessed area is physical ability, both fine motor and gross motor skills. Motor skills dictate which body parts can be used to control the wheelchair, the type of interface the client can control, as well as where the interface can be mounted on the wheelchair (Barker & Cook 1985), (Trefler, 1984). Gross motor skills help determine the clients' mobility goals. (Norgaard, 1986, Hildreth et al, 1980). As yet there are no studies which establish correlations between physical ability and driving an electric wheelchair.

In many centres, assessment of wheelchair driving focuses on functional performance. At H.M.M.C. there are several electric wheelchairs and a variety of interfaces used for this purpose. However most facilities have limited equipment for assessment purposes. (Pronk et al, 1980). Hildreth et al., (1982) have developed a manual on the methods they use to assess and train clients using electric wheelchairs. It is quite detailed and provides the clinician guidance in long term programming for clients. For a shorter assessment of driving ability Lotto et al (1984) developed a course performance test.

Several studies have focused on the development and use of microcomputer simulations for improvement in driving related skills. Sivak, et al. (1983) found improvement in standardized perceptual and cognitive tests after their subjects used a series of microcomputer based tasks designed for training driving related skills. Pronk et al., (1980) developed a computer program which simulated different models of electric wheelchairs in order to improve upon the assessment and prescription process of electric wheelchairs for physically disabled slients. They reported that their simulated testing encountered a number of difficulties, but held promise for further development. Basacchi, Naumann & Milner (1981) also developed a computer simulation program to facilitate objective evaluation of user and interface control for technical aids. Although these computer programs are now being developed as an adjunct tool to assess wheelchair driving, little has been done to quantify the relationship.

Method

In this study the battery of tests selected to assess skills postulated as being related to electric wheelchair driving included eight standardized tests for cognition and perception. These were:

1) Motor Free Visual Perception Test (Calarusso & Hammill, 1972)
2) Space Visualization subtest of the Southern California Sensory Integration Test (Ayres, 1962)
3) Coloured Progressive Matrices (Raven, 1965)

4) Picture Completion & Picture Arrangement subtests of the Revised Wechsler Intelligence Scale for Children (Wechsler, 1974)
5) Mazes subtest of Wechsler Preschool & Primary Scale of Intelligence (Wechsler, 1967)
6) Representative Stencil Design Test (Feurestein, 1972)
7) Peabody Picture Vocabalary Test (Dunn & Dunn, 1981).

The Peabody Developmental Motor Scales (Folio & Fewell, 1983) was used to asess physical ability. This test was standardized for both gross motor and fine motor skills.

The functional performance tasks included:

1) predriving tasks on an Apple IIe microcomputer
2) driving a Fortress Scientific 655FS electric wheelochair through the five courses designed by Lotto et al. (1984)
3) manoeuvering a remote controlled toy jeep through a scaled down version of the five courses
4) 'driving a wheelchair' through a two-dimensional microcomputer simulation of the five courses
5) 'driving a wheelchair' through a three-dimensional microcomputer simulation of the five courses.

For all functional performance tasks the subjects controlled either an 8 position direct switch joystick or a 6 position capacitative touchplate system. The touchplates were used by subjects who could not use the joystick.

These tests were individually administered to fifty seven youngsters over a one and one half year period. The sample included twenty four able-bodied children and thirty three physically disabled children who ranged in age from four to nine years.

Data Collection & Analysis

All functional performance tasks were designed with built-in microcomputer data collection facilities. All scores were transferred to a database and processed using SYSTAT a statistical analysis package. Correlations, ANOVA'S and regression analyses were carried out on the variables.

Different tests demonstrated significance with wheelchair driving between disabled and able-bodied subjects. Four measures that showed a significant relationship with driving for the physically disabled group were the Picture Completion subtest, the Motor Free Visual Perception Test, the Three Dimensional microcomputer simulation and chronological age. The four measures that demonstrated significance for the able-bodied group were the Peabody Picture Vocabulary Test, the Remote Controlled Jeep, the Two Dimensional microcomputer simulation and chronological age. The functional performance tasks were more strongly correlated to wheelchair driving than the standardized tests.

Summary

This study evaluated a battery of tests on a group of 57 children, both able-bodied and physically disabled. Thirteen tests were selected to investigate their relationship with electric wheelchair driving. Of these, three demonstrated a significant relationship for the physically disabled subjects, and a different set of three showed significance for the able-bodied subjects.

This study contributes to the understanding of which skills are related to electric wheelchair driving ability, and may assist clinicians in their assessment of clients for electric wheelchair driving potential. More work needs to be done in this area to investigate the differences in able-bodied and physically disabled subjects, and to develop an assessment protocol for use by clinicians.

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Classification of Wheelchair Athletes

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Introduction

Classification of wheelchair athletes enables even the most severely disabled to compete in a fair manner with other competitors with similar degree of disability. This allow for fair competition among athletes with great variation in the level of the lesion and degree of disability.

This system is not unlike the categorization of competitors in able-bodied sport like boxing and weight lifting where body weight is accepted as the significant factor for equalizing competitive performance.

Classification

The two systems used in the United States for classification of wheelchair athletes include an eight-class system as determined by National Wheelchair Athletics Association (NWAA) and three-class system used by the National Wheelchair Basketball Association (NWBA). The system of classification now being used by the NWAA in the United States is very similar to that utilized internationally(International Stokes Manderville Games Federation).

The NWAA system is based on neurological findings in which the residual musculature of the competitior is determined. The following muscle strength testing scale is used:

0: Total lack of voluntary contraction
1:Trace-faint contraction without movement
2:Poor-contraction with very weak movement through full range of motion when gravity is eliminated.
3:Fair-contraction with movement through the complete joint range against gravity
4:Good-contraction with full range of move movement against gravity and some resistance
5:Normal-contraction of normal strength through full range of motion against full resistance

The classes include three level of cervical lesions (1A,1B,1C).Class 1A and 1B are distinguished primarily by the strength of the triceps.Class 1B is distinguished from 1C by the motor function of the hand. Two levels involving trunk lesions(11,111) determined by the presence/absence of abdominal and back muscles assessed by sitting balance.

Two levels involvong lower limb innervation(1V,V)determined by spinal cord level and by the muscle testing points. The muscle point system is:

	R	L
Hip flexors	5	5
abductors	5	5
adductors	5	5
extensors	5	5
Knee flexors	5	5
exensors	5	5
Ankle flexors	5	5
extensors	5	5

Only muscle strength of 3/5 or greater is used in determinating total points.

For swimming competition, class V1 has been created as a subdivision of class V and is determined by muscle testing points score.

CLASS 1A

All cervical lesions with complete or incomplete quadriplegia who have involvement of both hands, weakness of triceps (up to and including grade 3 on testing scale) and with severe weakness of the trunk and lower extremities interfering significantly with trunk balance and the ability to walk.

CLASS 1B

All cervical lesions with complete or incomplete quadriplegia who have involvement of upper extremities but less than 1A with preservation of normal or good triceps (4 or 5 on testing scale) and with a generalized weakness of the trunk and lower extremities interfering significantly with trunk balance and the ability to walk.

CLASS 1C

All cervical lesions with complete or incomplete quadriplegia who have involvement of upper extremities but less than 1A with preservation of normal or good triceps (4 or 5 on testing scale) and normal or good finger flexion and extension (grasp and release) but without intrinsic hand function and with a generalized weakness of the trunk and lower extremities interfering significantly with trunk balance and the ability to walk.

CLASS II

Complete or incomplete paraplegia below T1 down to and including T5 or comparable disability with total abdominal paralysis or poor abdominal muscle strength (0-2 on testing scale) and no useful trunk sitting balance.

CLASS III

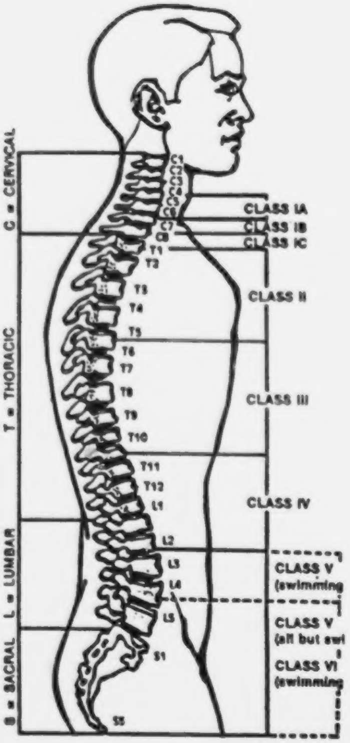
Complete or incomplete paraplegia or comparable disability below T5 down to and including T10 with upper abdominal and spinal extensor musculature sufficient to provide some element of trunk sitting balance but not normal.

CLASS IV

Complete or incomplete paraplegia or comparable disability below T10 down to and including L2 without quadriceps or very weak quadriceps with a value up to and including 2 on the testing scale and gluteal paralysis.

CLASS V

Complete or incomplete paraplegia or comparable disability below L2 with quadriceps in grades 3-5.



Swimming Events Only

CLASS V

Complete or incomplete paraplegia or comparable disability below L2 with quadriceps in grades 3-5 and with up to and including 39 points on the point scale.

CLASS VI

Complete or incomplete paraplegia or comparable disability below L2 and with 40 points and above on the point scale.

This classification system is most easily applied to complete cord injuries. Flexibility of approach is necassary in difficult cases e.g., poliomyelitis,incomplete cord injuries,multiple sclerosis, cerebral palsy, muscle diseases, connective tissue disorders or amputees. In poliomyelitis, for instance, it is generally agreed that the athlete has advantage over the traumatic paraplegic because of the presence of sensation and absence of spasticity. At the international level competition (ISMGF) an attempt is made to correct this advantage by applying a 5 point difference between polio and traumatic paraplegics, in determining the limits of class 1V,V and a 10 point difference between V and V1. In amputees, classification is carried out as follows:

The unilateral amputee (whether above knee or below knee) will be classified according to the above system (i.e., Class V1). Bilateral amputees will be classified as follows: Bilateral above knee-Class 1V and V (dependent on length of stump);above/below knee, Class V (dependent on length of stump);bilateral below knee, Class V1.

In addition, to judging muscle strength other factors important in classification are:

proprioception, sitting balance, spasticity, strapping, deformaties, arthrodesis (fusion of single or multiple joints), use of orthoses, training effect.

A player's classification is monitored periodically to keep pace with potential medical changes. Finally, the competitor must make every effort to coperate during the classifiaction examination.

This classifiation system provides guidelines for competitors in track, field, swimming etc.

The second system consists of a three-class classification used by the National Wheelchair Basketball Association (NWBA):

Class 1

Complete motor loss at T-7 or above comparable disability where ther is total loss of muscle function originating at or above T-7.

Class 11

Complete motor loss originating at T-8 and descending through and including L-2 where there may be motor power of hips and thighs. Also included in this class are amputees with bilateral hip disarticulation.

Class 111

All other physical disabilities as related to lower extremity paralysis or paresis originating at or below L-3. All lower extremity amputees are included in this class except those with bilateral hip disarticulation.

At no time during the game shall a team have players participating with a total of value points greater than twelve, nor more than three Class 111 players together at the same time.

When using either of these classification systems one must keep in mind that the purpose is to allow fair competition. Although no system is perfect a great deal of work has gone into providing the current system.

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STANDING AND ITS IMPORTANCE IN SPINAL CORD INJURY MANAGEMENT

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ABSTRACT

A broad spectrum of physiological problems are associated with lack of gravitational stress in the individual with spinal cord injury. Prolonged immobilization results in systemic de-adaptations which include cardiovascular changes, the alteration of calcium homeostasis which leads to bone de-mineralization, and risk of urinary calculi.

Weight bearing in the the standing posture has been shown to ameliorate many of these problems and offers physiological advantages for the individual with spinal cord injury.

There are also significant psychological and social benefits to standing, including improved self-image, and eye-to-eye interpersonal contact. Increased vocational, recreational and daily living independence are additional benefits of standing.

INTRODUCTION

As of 1980, there were over five million Americans with spinal cord injuries and five thousand to ten thousand new injuries occuring each year (36). While the impact of spinal cord injury on the individual in terms of health, employment and personal economics is inestimable, the economic cost to society in direct costs for medical and rehabilitation services, and indirect costs for loss of earnings and services was estimated in 1977 to be nearly three billion dollars (35). Improvement in long term management of spinal cord injury has immense importance for the individual and for society as a whole.

This paper is a review of the current literature relating to standing, weight-bearing, and related postural therapies such as tilting, in persons with spinal cord injuries.

The relationship between immobilization, and bone remodeling, has long been established (1, 2, 3, 4, 6, 8, 10, 12, 17, 18, 19, 32), as has the relationship between hypercalciuria and urinary tract calculi (1,13). Reversal or amelioration of these deleterious effects with weight-bearing has been documented in spinal cord injured (13, 18, 19, 20) and non-injured (10, 22, 27, 31) individuals, although the mechanism of improvment is not fully understood.

The role of standing and weight bearing is also explored in other complications of spinal cord injury with emphasis on effects of standing on the cardiovascular system, pressure sore development, spasticty and contracture, psychological and psychosocial functioning, vocational, daily living and recreational activities.

DISCUSSION

Mechanics of Weight Bearing and Bone Remodeling

Heaney showed that disuse osteoporosis results from active degradation of bone through calcium loss rather than failure of *bone formation* as was previously thought (17). Hypercalciuria concomittant with bone loss occurs in both healthy and traumatized individuals during prolonged bed-rest immobilization and weightlessness (1, 2, 3,4, 6, 8, 10, 12, 17, 18, 19, 32).

The relationship between calcium metabolism and the mechanics of weight-bearing are complex. Weight bearing has long been thought by many to be one of the most important factors in remodeling of the long, weight bearing bones (8, 9, 13, 18, 19, 27). Other factors include calcium, protein and other nutrient intakes (1), muscular contraction (1,7) and cyclic mechanical loading (24, 34).

Studies by Kaplan, Issekutz, and Freeman have shown passive standing and weight-bearing therapy to substantially decrease bone loss as measured by the difference between calcium intake and excretion (13, 18, 19, 20). Reversal of the bone loss experienced by astronauts after prolonged weightlessness occured after considerable time under normal activity under full gravity (10, 27).

Claus-Walker shows that hypercalciuria correlates closely to time after injury, with calcium lost at a high rate during the period immediately following spinal cord injury and generally reaching stasis (5). Claus-Walker reported that weight bearing did not lower hypercalciuria immediately (6), although an upright posture instituted with recently injured tetraplegic patients "improves their clinical status and shortens the duration of the ever-present hypercalciuria" (7).

Renal and Urinary Function and Standing

Urinary tract infection occured in 66% to70 % of persons with spinal cord injury during the initial medical/rehabilitation period, and an average of 37 % over a five year follow-up period according to Young (34). Clearly, this represents both a serious danger, and a significant cost factor in management of spinal cord injury.

Gould showed bladder pressure to be 2.5 to 3 times higher in the standing posture than in the supine position (16). Urine is drained more completely during micturation in the standing position, and residual urine reduced. Reduced residual urine reduces the incidence of bladder infections (37, 38).

Urinary tract calculi occur in spinal cord injured persons with high frequency (8, 34). Calculi in both bladder and kidneys have been shown to correlate strongly with hypercalciuria and immobilization (2, 5, 8) . Freeman reported the incidence of calculi was reduced in patients after attempted ambulation and weightbearing(13). Improved cardiovascular response to orthostatic stress also benefits the kidney funtion, as evidenced by increased or maintained glomerular filtration rate (30).

Weight bearing, Muscular Stretching and the prevention of Contracture and Spacticity

The limitation of range of motion caused by contractures has serious impact on mobility and independence for the individual with spinal cord injury. Other methods of preventing contractures, including manual therapy, are difficult and expensive to initiate and maintain as they require extended professional time. Leo sites a study by Odeen of patients discharged without access to physical therapy who maintained range of motion solely through passive standing (26).

Odeen and Knutsson measured the muscle tone of 9 people with spastic paraparesis before and after a regimen of stretching and loading (weight-bearing) and found that after weight bearing in the standing position spasticity in dorsal flexion was reduced an average of 32%, and in plantar flexion the reduction was 26%. By comparison, they found reduction after stretching in supine position to be only 17%.

Abramson's assertion that muscular contraction is the signal factor in preventing disuse osteoporosis (1) reinforces the need to continue support of research combining standing and weight-bearing with FES and other forms of exercise to develop a system for maximal conditioning.

Circulartory Benefits of Standing

People with spinal cord injury have insufficient orthostatic regulation by the nervous system. Stress on the heart due to standing induces a beneficial adaptation. Adaptation to repeated stress improves the cardiovascular response (26). Krebs postulates that "adaption of spinal man to the upright position may involve the recovery of a spinal vasomotor reflex involving the splanchnic circulation" (21). Figoni sites abdominal and thoracic pump, muscular contraction and improved tonus of resting muscles as factors in tilting which aid circulation (12).

Ragnasson has found the head up tilt position for quadraplegics to be "an effective method to reduce orthostatic hypotension by improving circulartory adjustment " as evidenced by the ability of quadraplegic patients to maintain glomerular filtration rate during head up tilt.(28). By implication, this population may acheive improved renal as well as cardiovascular function by standing.

Skin Breakdown and Pressure Relief
Pressure sores are second only to urinary tract infections in incidence of medical complications of spinal cord injury (11, 34), with costs for hospitalization due to severe pelvic sores averaging between $1760 and $4000 in 1980 (34).

To be effective in preventing skin breakdown and the formation of decubitous ulcers, pressure relief must be frequent, sufficient and preferably self-initiated (37, 38). Regular standing allows a more sustained period of relief to the sacral and ischial high-pressure areas of the buttocks than can be achieved by push ups. A device for standing at will through-out the day would provide greater pressure relief options to the user than a standing frame which is fixed in position. Air circulation during standing lowers temperature and humidity at the seating interface - both significant causal factors in pressure sore development (29).

Psychological and Psychosocial Benefits of Standing
Depression associated with negative self image has disastrous effects on the individual (with or without disability), psychologically as well as physically. The standing posture projects a proactive image of the whole person in the general social environment. It allows face to face conversations, and eye to eye contact, which can be effective in modifying both the self image of the individual and the response of others in the community.

Vocational Benefits of Standing
Standing greatly reduces the modifications to the workplace required for access to many jobs. Individuals are now in the workforce using stand-up mobility devices in diverse professions including the practice of surgery, machine operation, and employment as bank teller, beautician and teacher. The implied authority of the standing posture, with its negation of visual stereotypes has proven valuable to people in leadership roles such as business seminar leaders and university professors. Technology to facilitate standing within an academic or work environment represents an economical alternative for institutions and indeividuals that cannot afford to make permanent and most often expensive architectural modifications.

Standing and Activities of Daily Living
Independence in daily living and recreational activities is greatly enhanced by the increased range of reach available . Access to upper shelves and cabinets, appliance controls, ticket windows, automated teller bank machines are enviromnments that are more effectively approached while standing. In some cases, such as cooking at a hot stove, or operating dangerous power tools, the improved angle of view and unimpeded reach may be considerably safer. Technology to facilitate standing represents a cost effective method of adapting the person to the environment rather than customizing the home at greater expense.

Recreational Opportunities Afforded by Standing
The opportunity to recreate together with family and friends promotes relationships, self-worth and personal growth. Archery, bowling, and golf are a few of the sports for which standing may be the posture of choice, Often, however, standing is not an option due to lack of a device or system.

Devices and Systems for Standing
For the benefits of weight bearing, standing and postural therapies to be felt, technology must be available to facilitate them. Existing devices include stationary standing frames, manual and powered standing mobility devices, tilting boards and braces. While braces and brace-walking are often not seen as a functional *mobility* alternative, they are an important theraputic option, and may come to the fore in combination with FES in the future. Mobile standing devices in general offer more benefit psychosocially than do fixed location standing frames, and provide opportunities for standing throughout the day. More work in developing and deseminating such technologies is needed.

CONCLUSIONS

Spinal cord injuries have enormous physical, emotional and economic consequences for the individual and the society. Optimization of function and prevention of medical complication is of the utmost importance.

Standing has demonstrable value in many aspects of the management of spinal cord injury. The interlocking nature of physiological systems impacted by spinal cord injury sometimes make causal relationships difficult to establish, and further study is required to reconcile some conflicting results such as those of Claus-Walker (6), and Kaplan (19).

Development of devices and systems to facilitate standing is important. The combination of standing with other forms of exercise and conditioning, and with mobile capabilities are areas of great promise for further research.

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ANTHROPOMETRIC DATA FOR DESIGN OF SPECIALIZED SEATING AND MOBILITY DEVICES
A PRELIMINARY REPORT

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ABSTRACT

The purpose of the project has been to obtain critical anthropometric data that can be used by designers for improving the quality of body support in wheelchairs and other mobility devices for the disabled. This has been necessary since existing data from the non-disabled population is often inappropriate for designing for the disabled. To date approximately 140 subjects of all ages and common disabilities have been measured at both the University of Virginia and the University of Tennessee - Rehabilitation Engineering Centers.

The data collected has been analyzed for twelve variables considered to be of immediate interest. The initial results, although not sufficiently representative of the complete disabled population, illustrate the differences between non-disabled and disabled people in terms of critical body dimensions.

INTRODUCTION/BACKGROUND

Design of wheelchairs and specialized seating componentry often requires knowledge of body dimensions of people that actually use such equipment. Therefore, a cooperative project was begun in 1982 to systematically collect body dimensions and other anthropometric factors that would impact upon design (1). Measuring techniques and normal data were obtained from previous anthropometric studies (2 & 3). These techniques were largely duplicated except in those cases where deformity or body asymmetry prevented their use. In these cases alternate methods were developed and used. An attempt has been made throughout the data collection to have the same staff do the measurements in each facility in order to minimize any differences in techinque. Figure 1A summarizes the parameters measured and recorded.

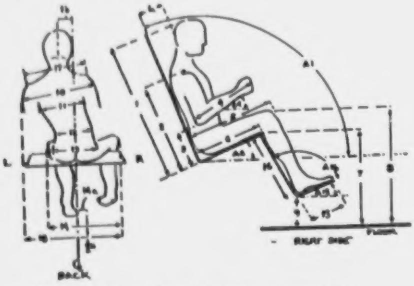

Figure 1A - Parameters recorded

RESULTS

Eighty variables have been collected and recorded on 139 disabled persons. Twelve of the more critical variables have received preliminary analysis. Analysis consists of computing: the age and/or diagnosis distributions plus; mean, standard deviation, minimum/maximum values, and 5th, 50th, and 95th percentiles for each of the 12 variables. The summarized results are displayed in chart form in Figures 1B - 12. Space limitations permit discussion on a few of the key variables.

Diagnosis and Age Distributions

The Diagnosis Distribution of the disabled population now residing in the data base is shown graphically in Figure 2. The age distribution is presented in Figure 1B. It can be noted that the cerebral palsy group constitutes the major category to date. The miscellaneous category inclues a variety of less common diagnoses. The Age Distribution has been divided into eighteen categories, with adults being lumped into two age categories; 19-30 and over 30. Obviously, many of these categories will require additional subjects in order to gain statistical significance. The rather fine division of age categories was necessary so that comparisons could be made to existing normal data. The final report, which will contain data on the disabled only, could use fewer age categories, thereby increasing the numbers in each category.

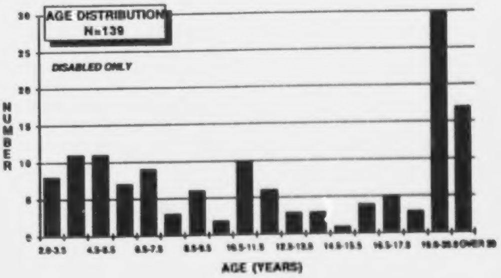

FIG. 1B

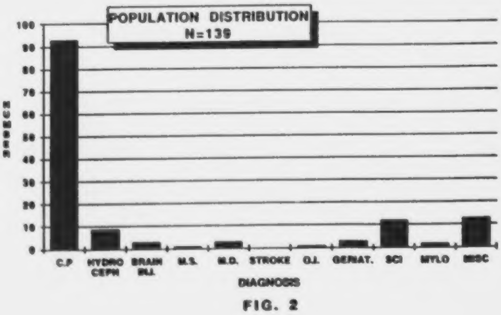

FIG. 2

Disabled versus Normal Results

Figures 3-8, present comparative values between normal and disabled anthropometric measurements on six seating variables. Examination of these mean value plots for the six variables indicates a significant difference between the normal and disabled measurements. The plots clearly suggest a trend of increasing difference with increasing age. It strongly suggests that the seating designs based on data from normals will create support surfaces that are consistently too large for the disabled population (Figures 4-8). Also significant differences can be noted in the body weights with increasing age (Figure 3).

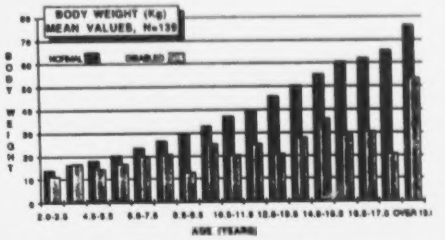

FIG. 3

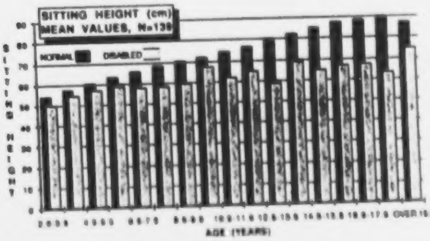

FIG. 4

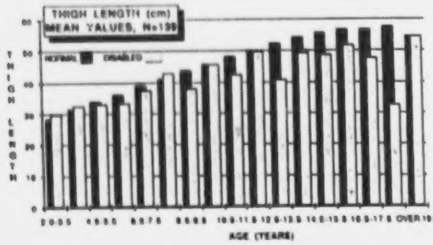

FIG. 5

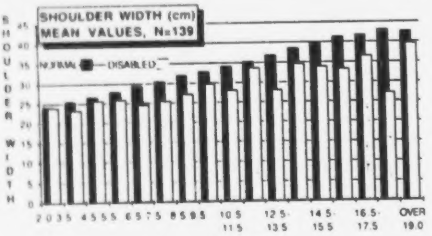

FIG. 6

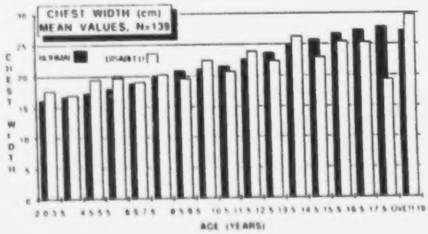

FIG. 7

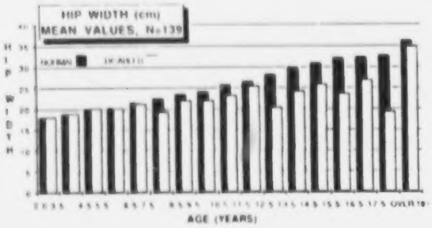

FIG. 8

New Data (Disabled Subjects Only)

Figures 9-12 contain data plotted from disabled subjects only. The data is currently not available from studies involving normal subjects. It is evident that broader age distributions could have been chosen. For example, an age distribution that is more consistent with the major lifestyle or activity level changes of the disabled population. This direction will most likely be taken when the final analysis and tabulation is carried out.

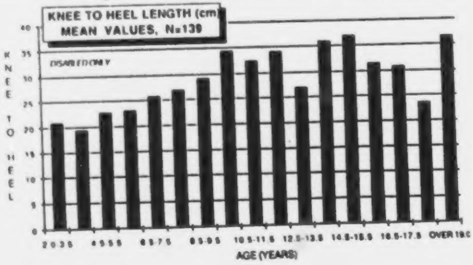

FIG. 9

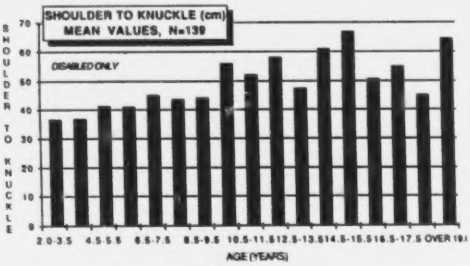

FIG. 10

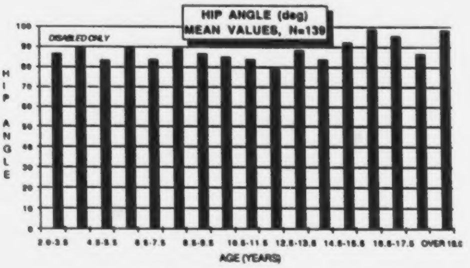

FIG. 11

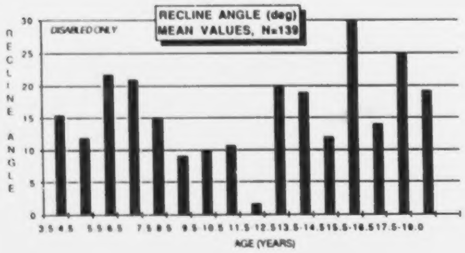

FIG. 12

Conclusions/Future Work

This study, although only partially complete, is significant for the following reasons. First, it will permit percent difference estimates on critical body measurments so that correlations can be drawn between normal and disabled anthropometric data when necessary. Secondly, it will provide mean and range values for critical body measurements such as; seat angle, back recline, shoulder to knuckle length and under knee to heel measurements that are not readily available from tables of normal data. And finally, although not presented above, dimensional requirements that are influenced by body deformity; such as spinal and pelvic deformity, knee and hip contractures, will be included in the data tabulated in the final report.

It is evident from the preliminary data that there are data deficiencies in many of the age categories. Also, from the viewpoint of statistical significance, caution should be exercised in using the existing data due to the insufficiency of data points throughout various age and disability categories. Work is currently underway to expand the data base to approximately 400 subjects with emphasis on those categories which presently contain the smaller numbers of subjects.

Further efforts at data analysis will emphasize the influences resulting from severe disabilities. The ultimate goal is to prepare a final technical report that will provide age and disability anthropometric tables that will be useful in the design of specialized seating and mobility devices.

ACKNOWLEDGEMENT

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SPEED REGULATION IN HAND RIM WHEELCHAIR PROPULSION

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ABSTRACT

Adaptation to different velocities in hand rim wheelchair ambulation was studied in terms of timing, work per cycle and push angle. Speed regulation is achieved both through adapting cycle frequency as well as the amount of work per cycle. Moreover a higher cycle frequency is mainly attained by adjusting push time. No systematic changes in push angle are seen. These findings most likely imply adaptation in the pattern of torque generation. The results hold for a group of trained wheelchair sportsmen at a daily-use speed level (.56 - 1.39 m/s) as well as racing speeds up to 3.33m/s. The results were confirmed for wheelchair propulsion in a basketball wheelchair and a racing wheelchair, the latter with different hand rim diameters.

INTRODUCTION

Propulsion technique of hand rim wheelchair ambulation is badly understood. To our knowledge no systematic research has been conducted into timing pattern, work per cycle and push angle with respect to power output, velocity and overall resistance. This rather complicates interpretation of parameters on timing and movement technique with respect to other experimental conditions, such as seat position.

Few studies have incorporated timing parameters. Only cycle frequency was determined rather frequently (1,2,3,4,5, 6). Brubaker and McLaurin (2) studied push angle, cycle time and torque applied to the hand rims in relation to seat position at V=2.5km/hr. Walsh et al. (5) analysed cycle time in wheelchair sprinting, with respect to seat position. Sanderson and Sommer (4) studied timing and movement pattern of the upper limb and trunk in the sagittal plane.

Moreover in wheelchair racing several propulsion techniques are used. It is not feasible to advise a suitable technique in wheelchair ambulation for a given subject or condition, until a detailed description and analysis of wheelchair propulsion technique is available.

Results of two current projects, in which propulsion parameters were studied next to physiological parameters, will be discussed below.

METHODS

Two hand rim wheelchair experiments (EXP) were conducted on a motor driven treadmill (MDT). Parameters of propulsion technique were determined in relation to mean wheelchair speed. The mean amount of work per cycle (A) for both arms was derived from the external power (P) and Cycle Time (CT), according to:

$$A = P \times CT \quad (= \int M.dQ)$$

P was determined in a drag test on the MDT (7), according to:

$$P = F \times V$$

in which F is the mean drag force and V the mean wheelchair velocity of a subject wheelchair combination. CT was calculated from cycle frequency (CF(Hz)). From film data the Push Angle (PA) of the left hand with respect to the wheel axis, Push Time (PT:"time on hand rim") and Recovery Time (RT = CT - PT) were determined. Relative values (%CT) for PT and RT were derived from mean values.

In EXP-1 N=6 male wheelchair sportsmen (mean age:35.6; s.d.:+/-6; mean body weight: 78.5 +/-7) conducted four 12 minute exercise tests in their basketball wheelchair. In each test, the belt speed increased with .28m/s every third minute, from .56m/s to 1.39 m/s. The slope of the treadmill was kept constant in each of the four tests at respectively 0,1,2 and 3 degrees. The tests were assigned randomly per subject.

In EXP-2 N=6 male marathon wheelchair racers (mean age:28.2 +/-6; mean body weight:70.5 +/-16.5) conducted five 12-minute exercise tests in a "Speedy Wheely" racing wheelchair. Different hand rim diameters were mounted to the spokes in the five tests (.3m,.35,38,.47,.56m). Speed increased with .83m/s every third minute, from .83m/s to 3.33 m/s. The slope of the MDT was constant (.5 degrees).

Data were statistically analysed with a multi-factor analysis of variance for repeated measures (P=0.05), with the exception of PT,RT and PA in EXP-1. The latter was due to incomplete data and the parameters were analysed qualitatively.

RESULTS

The results for both experiments show a similar trend: an increasing speed (and subsequently P) is generated through a definite decrease in CT, as is shown for EXP-2 in Figure 1.

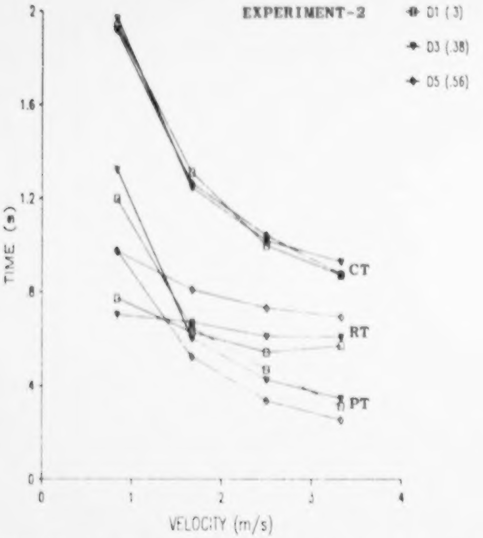

Figure 1. Mean CT,PT and RT for 3 hand rims (EXP-2).

In conjunction with a decrease in CT a definite increase in the amount of work per cycle is seen in both experiments (Fig.2.).

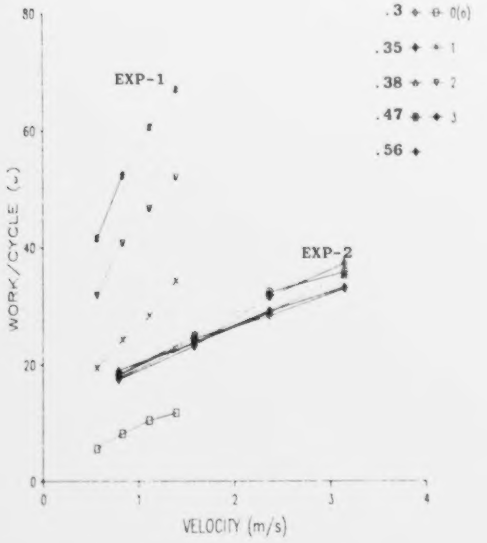

Figure 2. Mean A for EXP-1 and EXP-2.

PA ranged at a more or less constant level. (EXP-1: 65-80, EXP-2: 110-160 deg.) and showed no significant relation with propelling velocity (Table 1).

	EXP-1			EXP-2		
	Velocity	Slope	VxS	Velocity	Diameter	VxD
CT	*	*	*	*	ns	ns
A	*	*	*	*	ns	ns
PT	-	-	-	*	ns	ns
RT	-	-	-	*	ns	ns
PA	-	-	-	ns	ns	ns

(*): p=0.05; -: not tested
ns: not significant

TABLE 1.

A lower CT with increasing wheelchair velocity is predominantly attained through a decrease in PT (Fig.1.), although a significant decrease in RT is seen as well (Table 1). Moreover a decrease in relative PT (%CT) and an increase in RT (%CT) is seen in both experiments (Fig.3.).

Contrary to our expectations no significant variation with respect to hand rim diameter was seen for any of the parameters in EXP-2 (CT,A,PA, RT and PT; Table 1.). A clear effect of slope level was however confirmed for CT and A in EXP-1 (Table 1.). This leads to an increased PT (%CT) and a decreased RT (%CT) with increasing slope (Figure 3a.).

DISCUSSION

Our data on CT agree well with previous studies (1,3,6). However in contrast with the linear relations described in these studies, a clear curvi-linear relation is evident in our data (Fig.1). Moreover the trend in the "time on hand rim" (PT) agrees with (5) and shows a similar dominant trend with increasing velocity as was described for the period of force-transmission (FT) by Lesser (3). This implies that both parameters (PT, FT) are more or less congruent.

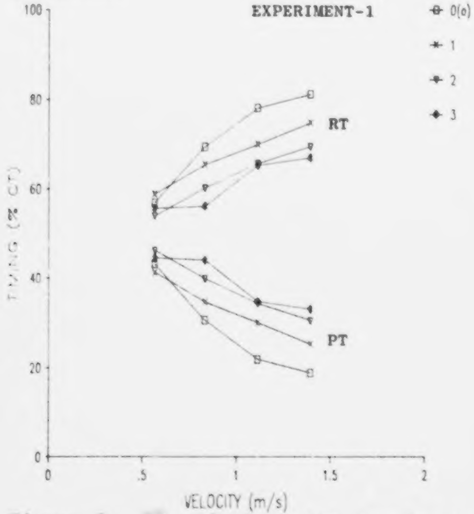

Figure 3a. PT and RT in %CT for EXP-1

Speed adaptation is also evident in A. Since no speed adaptation in PA is apparent and a shorter PT is seen, the increase in A implies a change in the pattern of force generation. An increase in torque (M) and instantaneous power is likely. This will be verified in near future with a wheelchair simulator with force registration.

Both absolute and relative values of PT show its prevailing speed-regulating characteristic. The declining pattern in PT(s) seems closely related to the required acceleration of the hand in the phase of force generation.

The small but significant diminishing trend in RT (Figure 1.) stresses the dominant declining curvature of PT in relation to CT. Whether this trend in PT is cause or effect of the CT pattern is unclear.

The findings in EXP-1 with respect to velocity and slope, indicate that timing (CT,A) is relevant in power generation in general. This can be seen in the slopes of the lines in EXP-1 in Figure 2. and may be reflected as well by the significant statistical interaction between slope and speed (Table 1.).

For a given slope (EXP-1) and hand rim diameter (EXP-2) no clear changes are seen in PA with increasing speed.This indicates a trajectory of the hand, independent of wheelchair velocity. Between different slopes and hand rim sizes no changes were seen in PA for a given speed as well. The latter indicates an increasing hand-trajectory for a larger hand rim diameter (EXP-2).

Adaptation to different hand rim sizes is clearly independent of timing. Movement analysis of arm and trunk might indicate other speed-regulating mechanisms in this respect.

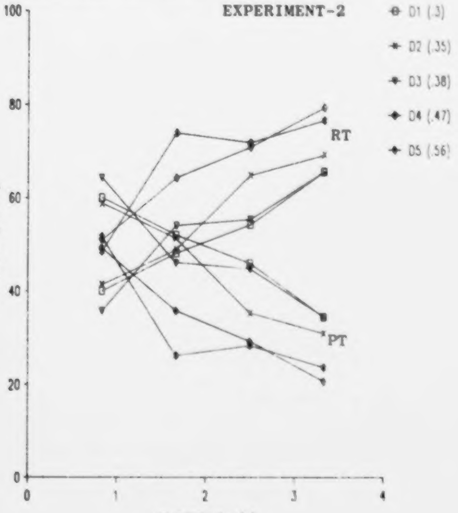

Figure 3b. PT and RT in %CT for EXP-2.

The differences in relative PT and RT between EXP-1 and EXP-2 (Figure 3.) may be due to the difference in wheelchair configuration which leads to a differentiation in the distance between shoulder and wheel axis.

CONCLUSIONS

For a large velocity-range, two wheelchair configurations and a group of wheelchair sportsmen,the speed-regulating character of several propulsion technique parameters (CT,PT,RT,A) was clearly shown. No PA changes were found. A predominance is seen for PT in adapting CT to a given velocity. This holds for wheelchair sportsmen, propelling a basketball and racing wheelchair with different rim sizes.

Timing parameters appear relevant in adapatation to slope increments as well. This implies a depence on external power output in general.

The results of EXP-2 show the independence of timing parameters in the adaptation to different rim diameter. The impetus of these findings on force generation and movement technique must be studied in more detail.

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A SPATIAL MUSCULOSKELETAL MODEL FOR WHEELCHAIR LEVER PROPULSION

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ABSTRACT

The development process for a dynamic, spatial musculoskeletal system model for simulating the wheelchair lever propulsion function is described. A 3-Dimensional model of the skeletal system and its correlation with experimental data are presented.

INTRODUCTION

A comprehensive musculoskeletal model which simulates the dynamics of the wheelchair propulsion function can provide a variety of benefits, including:

- Optimization of the wheelchair mechanical system parameters such that these parameters are customized to a specific operator;
- Determination of the joint forces and the propulsion effort required to propel the wheelchair;
- Development of an understanding of the function of individual muscles during the propulsion cycle.

A research project at the University of Virginia Rehabilitation Engineering Center (REC) and the Center for Computer Aided Engineering (CCAE) is currently developing such a model with the longer term goals of creating a wheelchair prescription software system and quantification of muscle functions.

MODELING ISSUES & APPROACHES

The modeling considerations include:

Modeling of the Skeletal/Joint System - The geometric constraints and the force compliance of the upper extremity musculoskeletal system must be appropriately represented in the model to reflect the various motion and joint force patterns which are known to occur during the wheelchair propulsion process. The motion in each joint in the musculoskeletal system can, in general, be represented by two contacting surfaces undergoing relative rolling and sliding motions in 3-dimensions. Kinematically, these joints are higher pairs, i.e., cam-like pairs. The initial modeling process in the current project has concentrated on modeling these joints with lower pair representations, such as the spherical and the revolute joints; the resulting gross motion behavior is then compared with the gross motion behavior measured on the computerized test data acquisition system built at the REC to iteratively refine the model. This test data acquisition system is shown in Figure 1.

Individual Muscle Forces - The force exerted by a muscle on its points of attachment depends upon a number of factors, including the length and cross-section of the aggregate fibers, the rate of contraction, the geometric orientation of fibers with respect to their tendon plates, the geometric orientation of muscle axis with respect to the joint axis and the state of neural activation of the muscle. The modeling process described in this paper is directed toward synthesizing the appropriate published research results and modeling procedures for the force generating capabilities of individual musculotendon elements into the simulation software. The dimensionless model of (1) and the quantitative model for muscles (2) are likely candidates for these modeling procedures. The selected modeling procedure for individual musculotendon elements will be applied to the muscle parameters - i.e., muscle fiber lengths, muscle length to fiber length ratios, number of sarcomeres per fiber (at both ends and at middle of the muscle belly), pennation angle, and volume. For correlation and validation of the musculoskeletal system model, the subjects utilized for tests at the wheelchair experimental facility will have Magnetic Resonance Imaging (MRI) scans from which specific muscle parameters for the musculotendon model will be extracted. Figure 2 shows the overall procedure planned for this data extraction process, in conjunction with a force model for individual musculotendon element. In order to confirm the validity of the procedure of Figure 2, the MRI scans on one cadaver have been obtained, and the cadaver has been dissected to obtain the actual muscle parameters for comparison with the data extracted from the geometric models.

Muscle Coordination Algorithms - In addition to the issue involved in modeling the individual musculotendon element, the modeling of the load sharing between the various muscles at each instantaneous configuration of the musculoskeletal system requires consideration of the complex interactions of the neurological, the muscular, and the skeletal subsystems. A large body of literature already exists on the methods to solve the redundancy problem of muscular load sharing and the combined dynamic solution of the skeletal-link-mechanical and the musculo-mechanical parts of the total model. The model development process is directed to synthesizing existing approaches as appropriate for the wheelchair propulsion function.

System Dynamics Algorithm - the dynamics of the system are being modeled by the Lagrangian formulation based on the (4 x 4) matrix approach of Denavit-Hartenberg as extended in (3). The total system model is envisioned to comprise simultaneous differential equations representing the skeletal-link-mechanical and the musculo-mechanical parts, algebraic equations representing the geometric constraints of the joints, and appropriate muscular load sharing algorithm, all operating under a numerical integration scheme.

SPATIAL SKELETAL-LINK MECHANICAL MODEL

The initial modeling effort has concentrated on developing a 3-Dimensional model to simulate the lever propulsion function on the experimental facility of the REC (Figure 1). While the test data generally indicate that the shoulder point experiences significant motion the initial model assumes that the trunk is fixed. The shoulder joint is modeled as three intersecting, orthogonal revolute joints as shown in Figure 3. The elbow is modeled as a revolute joint whose axis is normal to the plane formed by the three points represented by the shoulder, the elbow, and the wrist. The wrist is modeled as a spherical joint connecting the forearm to the hand. The hand gripping the lever is modeled as a cylindrical joint The lever is revolute connected to the ground with the fixed revolute axis in the transverse (X axis) direction.

While a goal of this modeling effort is to produce a stand-alone software system, much experimentation with the skeletal-link model is expected before the finalized skeletal-link model is utilized to develop the equations of motion. Therefore, at this stage of the model development process, it was decided to utilize a commercial CAE software system for mechanisms and linkages. Three well known systems - IMP, ADAMS, and DADS - are available for this purpose. The current model utilized the IMP system. This permits a quick way to iteratively refine the model by adding and deleting links and experimenting with different joint types. Further, during the dynamic analysis stage, these CAE systems would provide convenient analysis tools and also serve as another correlation and validation avenue for the completed stand-alone software system. The IMP system also internally utilizes a matrix rank procedure to determine the degrees of freedom, i.e., the number of independent motions in the model, and also selects the most appropriate generalized coordinates as independent variables. This capability is particularly useful during the early stages of model development.

The model of Figure 3 is a 4 degrees of freedom system with the 3 shoulder angles and the elbow rotation utilized as the input variables. Figure 4 shows the comparison between the model predictions and test data for the wrist locations during the lever propulsion cycle.

If the four input rotations are associated with the four motor torques, the mechanical advantages from these motors, as they apply to the output torque at lever rotation can be computed from the velocity ratios, or the partial derivatives. Figures 5 shows these mechanical advantages corresponding to shoulder rotation θ and elbow rotation. If muscles are modeled as line forces, these muscles produce generalized torques at the input rotations, which in turn are applied to produce the external work such as the lever rotation. The implication of generalized torques on muscular load sharing strategies is currently being evaluated.

CONCLUSIONS

A spatial skeletal-link model for the wheelchair lever propulsion has been developed and validated for gross motion behavior. Generalized muscle forces and mechanical advantages may provide an algorithmic approach to muscular load sharing. The overall model development process for the musculoskeletal system has been defined and further work is currently underway to develop the comprehensive model, with the associated stand-alone software as an aid for wheelchair prescription.

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FIGURE 1

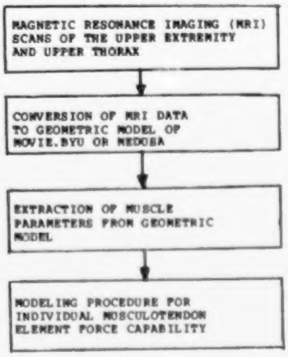
MAGNETIC RESONANCE IMAGING (MRI) SCANS OF THE UPPER EXTREMITY AND UPPER THORAX
CONVERSION OF MRI DATA TO GEOMETRIC MODEL OF MOVIE.BYU OR MEDUSA
EXTRACTION OF MUSCLE PARAMETERS FROM GEOMETRIC MODEL
MODELING PROCEDURE FOR INDIVIDUAL MUSCULOTENDON ELEMENT FORCE CAPABILITY

FIGURE 2

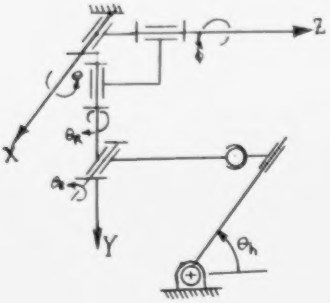

FIGURE 3

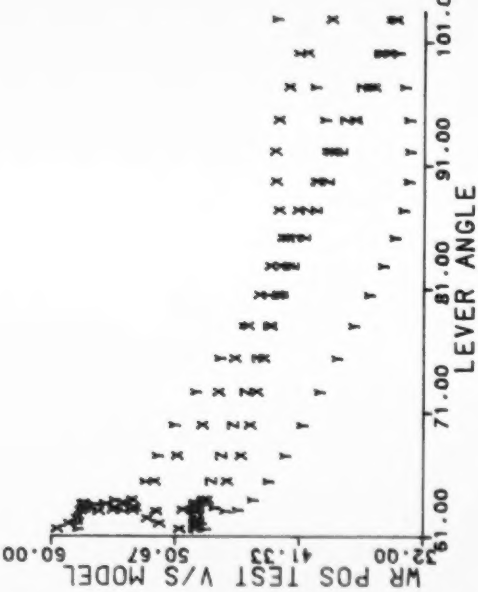

FIGURE 4

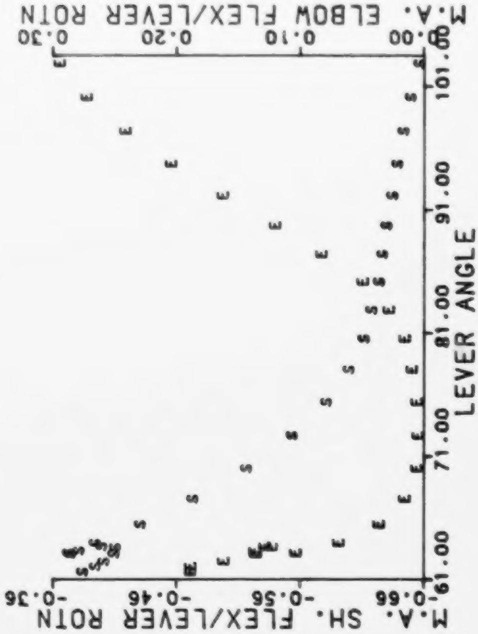

FIGURE 5

A CUSTOM WHEELCHAIR WHICH ALLOWS FOR LEG-ASSISTED PROPULSION

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University of Virginia Rehabilitation Engineering Center

ABSTRACT

This paper describes a modular seating and mobility system designed for an individual of short stature. He has a unique combination of abilities and limitations resulting from Osteogenesis Imperfecta. The design utilizes the approach of having a two-part system: the base, and the seating component. The first part of the paper examines the needs of the individual and the problems with his present system.

INTRODUCTION

The world is not designed for people who use wheelchairs or for those under five feet tall. If you happen to fall into both of those categories, it becomes even tougher, because wheelchairs are not designed for people of short stature or irregular proportions. The individual for whom the system described in this paper was designed, N.B. is an adult of short stature who can use his legs to assist in ambulation, but cannot walk independently.

PROBLEM AND NEEDS IDENTIFICATION

User Description

As stated previously, N.B. is an adult of short stature. His medical diagnosis is Osteogenesis Imperfecta. Conditions resulting from this include his short stature, poor balance, bowed extremities, a leg length discrepancy, arthritis, and a general weakness in his muscles. He has recently reported an increase in pain in his hips and elbows. He can walk without assistance for very short distances (6-10 feet) but prefers not to due to his fear of fracturing a bone should he lose his balance and fall. He has not had a fracture in thirteen years, but as he ages, the chances will increase due to osteoporosis. He encounters problems daily related to his physical disabilities, his stature, and using a wheelchair.

He is independent in mobility at this time, although transferring his present wheelchair into his car presents a problem It weighs about 45 pounds and this exacerbates the pain in his elbows.

Present System

The mobility system he presently uses is a standard adult-sized wheelchair with the large wheels up front and rear casters. He sits on the front edge of the sling upholstery and uses the handrims and his feet to propel the wheelchair. The fact that he aids in ambulation with his feet is something we chose to preserve in the new design, as the exercise serves to strengthen his bones and benefit his respiratory and cardiovascular systems as well [1].

By using the handrims in his present system, his elbow and shoulder joints have taken quite a bit of abuse. His chair has 24" wheels, and at the top of his stroke his shoulders are abducted to about 70 , and his elbows are flexed at least 90 The seat depth is 16" and his own sitting depth is 14", so if he chooses to sit back in his chair, the popliteal region is compressed causing his feet and toes to go numb. This also results in a kyphotic sitting posture. The armrests are full-length, non-removable, standard height. When he sits in his wheelchair, they are about 2" below his armpits. If he uses them, he compresses the area just above his elbow, and his hand falls asleep (fig.1).

Present System

Figure 1.

The folded size and weight of the wheelchair make it difficult for him to transfer it into his car.

Synopsis of Needs

N.B. needs a seating and mobility system which meets the following design criteria:

- allows for propulsion by means of his arms and legs
- lightweight and easily transferred into his car
- fits his body
- aesthetic
- durable
- provides a sitting height which fits into a business setting
- gives a stable surface from which to reach for things

Commercial Availability

The only commercially available system which would allow for the large wheels in front was not acceptable because of the weight (45 pounds). Another approach considered was using a lightweight base, but given the extent of the modifications and the initial price, this was dismissed as too costly.

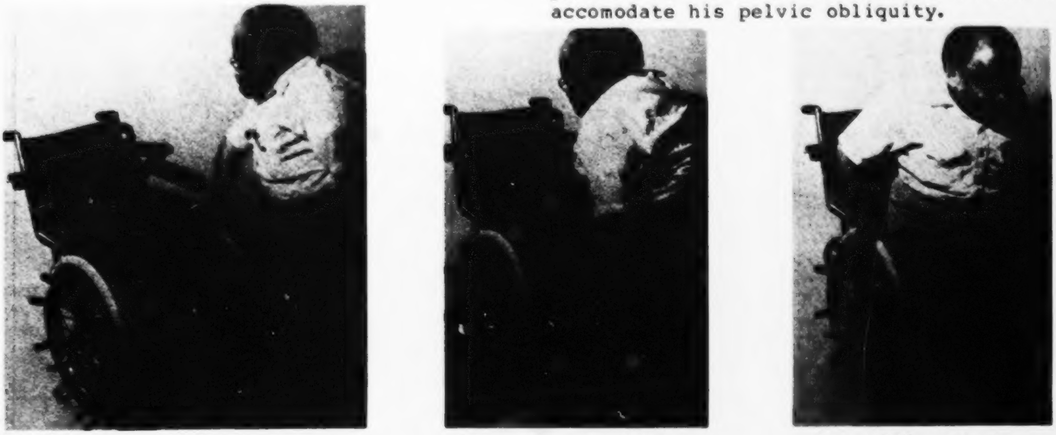
METHODOLOGY

The following steps were taken in the design development process:
1. A letter was written and sent on my behalf to Stainless to request support for my project. Approval was granted for assistance in parts, labor and fabrication of the final product.
2. I conducted interviews with N.B., visited his workplace, observed his techniques in moving around, transferring his wheelchair into the car, working and reaching. Took body measurements.
3. Consulted with P.T. department in an analysis of his medical condition, his needs for mobility, and reviewed his most recent P.T. evaluation.
4. Found very little literature available on seating and mobility for people of short stature. Reviewed reports and literature on wheelchair design [2,3,4,5].
5. Contacted O.I. groups, Little People of America, and professionals who specialize in working with people of short stature to research alternatives and get further insight into the problem.
6. Constructed a testing device to determine the best location for N.B. in relation to the axis of the front wheels. Tested single vs. dual rear caster performance and stability of single caster system.
7. Made prototype bilevel seat; one level to propel from, the other to sit on.
8. Came up with several design options and requested critique from others.
9. Drew up detailed shop drawings for prototype.
10. Testing of design should be accomplished by mid-April. Revisions will be made to the drawings and they will be sent to Stainless for manufacture of the final product.

DESIGN SOLUTION

The resulting design consists of a 2-part lightweight foldable system (a base and a seating component) which meets his unique needs in propulsion and fits his body (fig. 2). The prototype weighed in at 28 pounds, 10 pounds of which was the tires and caster. The advantage of the two-part system comes in the reduction in the weight he will be lifting at one time. The heaviest part is the base (with the wheels, it weighs 18 pounds). He was consulted in the choice of color, upholstery, and the decision to go with a single rear caster. The design is flexible enough to accomodate a change to a dual rear caster system if he so desires.

Seating Component
The back and seat unit includes the following features:
Bi-level seat.
One level is for a regular sitting height, the other is for sitting on while moving. The regular surface is a foam and plywood seat to provide comfort and stability. The lower level is exposed by flipping the front half of the regular seat on top of the back half (fig. 2). This two-part cushion is enveloped in cordura upholstery with a reinforced area in the hinging region. In its flipped mode, it provides a back support for N.B. while he is moving. The lower level is located in the optimal position for N.B. with respect to the handrims. It is padded with a denser foam and is formed to accomodate his pelvic obliquity.



Approaching Chair

Flipping Seat Back

Propelling Chair

Figure 2. Custom Wheelchair -- Prototype
(handrims shown will not be used)

Back.

The back is connected to the seat by a channel and pivots forward to fold down on top of the seat when removing it from the base. The back upholstery tension is adjustable by means of velcro and webbing. This eliminates the sagging problem common to standard upholstery. The swingaway armrests are wide and padded. The armrest block acts as a stop in both positions. There are handles for assisted propulsion.

Base Unit

The base consists of a lightweight, foldable frame with 20" wheels, oval handrims, and a single rear caster (fig.3). The 20" wheels cut down on the degree of flexion required to proplel the chair. In the testing we performed in the design stages, the single caster proved to be more maneuverable than two rear casters without compromising stability. Footrests are height-adjustable and fold out of the way. To fold the base,you lift up on the crossbar and the rear members swivel as it folds.

Attachment Mechanism

A channel guides the seat into its lateral position, offering more lateral stability to the chair as a whole. A hook from the lower level and a mating stop on the frame locate it in its forward postition. Once in postion, the backrest is swung up into place and it locks with a spring-loaded latching mechanism.

MATERIALS

Chrome-molly and aluminum were chosen for their strength-to-weight properties. The cordura upholstery was chosen for its wear characteristics and aesthetics. Pneumatic tires were chosen for rider comfort.

CONCLUSION AND FUTURE DEVELOPMENT

This paper has given an example of a system designed for one individual, but there are several noteworthy design considerations, ideas, and implications that came out of this process for me:

1. A lightweight transfer accomplished by the choice of materials and a two-part system.
2. The potential use of a generic base and a specific seating component in future designs.
3. Potential for a modular wheelchair kit; use of various components which, when put together in different arrangements, could result in consumer options as far as frame and seat height, width and depth, wheel and caster configurations,etc.. The consumer and professional could order different components, mixing and matching to come up with an appropriate base and seat.
4. The need to look at the effect of dynamic as well as static design on the individual. In N.B.'s case, I feel the condition of his elbows is directly related to the inappropriate size of his tires.

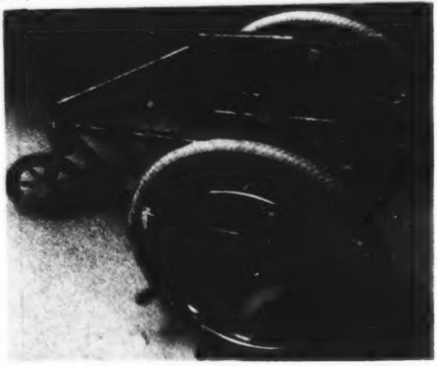


Figure 3. Base Unit

ACKNOWLEDGEMENTS
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USING A TIME DELAY TO ALLEVIATE HEAD OSCILLATIONS WITH AN ELECTRIC WHEELCHAIR

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ABSTRACT

Individuals who control an electric wheelchair with a head switch can experience episodes of repeated oscillations, sometimes referred to as "bucking." A computer simulation of wheelchair movement and several empirical experiments suggest that the addition of a short time delay between switch closure and the beginning of wheelchair movement can reduce this tendency for oscillation.

INTRODUCTION

People with poor movement control caused by severe disability sometimes use a head-activated switch to control the movement of an electric wheelchair. Normally these people push their heads back to operate a head switch, which activates propulsion motors that drive the wheelchair forward. Under certain conditions it is possible for a perturbation to initiate a series of head oscillations that start and stop the wheelchair in quick alternation, a phenomenon called "bucking." The oscillations are at best annoying, and at worst may result in loss of control of the wheelchair for several seconds. Therefore, research was conducted to find an inexpensive way to alleviate bucking.

COMPUTER SIMULATION

The particular wheelchair used throughout this study was an Everest and Jennings Model 3P. For the purposes of modeling (1), the wheelchair was decomposed into three major subsystems -- the drive voltage shaping circuit, the motor, and the mechanical linkage to the wheels.

1. The drive voltage shaping circuit is activated by the wheelchair occupant leaning back to close a head switch. The circuit's output is a series of 24-volt pulses that drives the motor. In order to accelerate the wheelchair gradually, the duration of these pulses are gradually increased until they reach some maximum steady-state value. The initial pulse duration, the rate of pulse-width increase (ramp or exponential), and the maximum pulse duration are all adjustable parameters of the wheelchair.

2. Application of the voltage pulses to the motor produces an armature current. The torque produced by the motor is proportional to this current. In order to calculate the armature current, the motor was modeled as a series combination of a resistance, an inductance, and a back electromotive force that was proportional to the motor's angular velocity. A diode in parallel with the motor permitted armature current to continue to flow during the intervals between successive pulses.

3. The torque produced by the motor is transduced to the back wheels by a mechanical pulley linkage. The ratio of the wheel pulley radius to the motor pulley radius determines the applied torque. The angular acceleration of the back wheels is in turn determined by this applied torque, the wheel-floor reaction torque, and the torque due to coulombic friction. The effective moment of inertia is partially due to the motor pulley and partially due to the wheels themselves.

The model parameters were empirically derived from measurements of the electro-mechanical properties of the component elements. From the concatenation of the three subsystems one can calculate the position, velocity, and acceleration pattern of the wheelchair as it starts. The velocity pattern was empirically validated (1).

The next step was to model the interaction of the wheelchair and its occupant. The wheelchair acceleration produces a force which affects the head position of the wheelchair occupant. The movement of the head in contact with the head switch and wheelchair back was modeled as a second-order underdamped system. It was assumed that the person applied a step-like increase in neck force to close the head switch. If one also assumes that the head is highly underdamped, then significant oscillations are created by both the initial neck force used to close the switch and by the resulting acceleration of the wheelchair. If these oscillations reinforce each other, the head may come off the switch. However, the relative phasing of these oscillations can be altered by introducing a short delay in the activation of the wheelchair after the head switch is closed. The simulation suggested that a delay of around 0.3 s might cause a partial cancellation of these oscillations, and hence avoid bucking.

EXPERIMENT 1

The next step was to experiment with individuals without disabilities to see if the introduction of a short delay would have the effects suggested by the computer simulation. Individuals sat in an electric wheelchair and caused the chair to accelerate forward by pressing back against a head switch. The wheelchair was driven over a "bump" on the floor, and the experimental hypothesis was that there would be fewer head oscillations when there was an added delay between the switch closure and the motor activation. This measurement approach failed because these people were able to tense their neck muscles and resist head oscillations under all the experimental conditions, with and without added delays.

A more sensitive experimental measure was needed. People were asked to make their heads oscillate deliberately, and the delay between switch closure and motor activation was varied to determine which values of delay would facilitate oscillations. If one imagines the head to be like a mass on a spring, then when people resist oscillations (as in the previous manipulation of riding over a bump), they probably change the dynamic characteristics of their muscles to effectively damp the spring and/or provide volitional forces to counteract perturbations of head position. In contrast, if someone is asked to deliberately try to let their head oscillate, the effective damping is probably reduced and/or the person relaxes so as not to oppose the perturbing forces. It was hoped that this latter situation would more sensitively reveal the effects of varying the delay.

Method

One male and three female subjects between the ages of 25 and 39 served as subjects. They had no apparent movement disabilities. Subjects were instructed to try to make the wheelchair oscillate so that it would repeatedly toss their head off of the head switch. The Treadlite switch had negligible over-travel beyond closure. Two values of delay were used. In the short delay condition, there was a 0.10 s delay between switch closure and motor activation ("make" delay). This delay was primarily due to a debouncing capacitor and a relay. In the long delay condition, an electronic timer lengthened the "make" delay to 0.29 s. In both conditions there was a 0.06 s delay between the switch opening and the removal of the drive voltage to the motor ("break" delay). Once triggered by the closing of the head switch, the electronic timer was insensitive to the state of the head switch until the pre-set delay period was completed. However, at the instant the delay was completed, the head switch had to be in the closed state for the motor to be activated.

For each of the two delay conditions, subjects practiced deliberately bucking for five minutes before performing a sequence of ten 7-second trials. On a second day, subjects performed another ten trials in each condition. The order of conditions was counterbalanced across subjects and days. A strip chart recorder was used to measure when the subject's head came forward enough to open the head switch. The temporal pattern of switch openings and closings was used to characterize bucking behavior.

Results

In the short delay condition, subjects typically exhibited strings of more than 25 successive bucks at a rate of a little over 4 Hz. Strings of at least eight successive rapid oscillations occurred on about 86% of the trials with the short delay. In contrast, in the long delay condition, subjects typically exhibited less uniform patterns of oscillation with an average frequency slightly below 2 Hz. Pauses of more than 0.5 s were frequently interspersed among these oscillations. Three of the four subjects rated the short delay system as easier for producing bucking behavior. The added "make" delay thus appeared to disrupt a high frequency resonance mode of oscillation. The next step was to experiment with individuals having quadriplegia.

EXPERIMENT 2

Method

One 50-year-old female with quadriplegia due to polio served as a subject. She normally used a sip-and-puff control. However, in this experiment she used the same head switch as in Experiment 1. Her wheelchair had an inherent "make" delay of 0.03 s due to a relay, and virtually no "break" delay. The "make" delay was experimentally lengthened by an electronic timer.

The subject received blocks of five trials. Each block consisted of one practice trial, followed by three trials in which the subject was instructed to buck deliberately, and one trial in which the subjects were instructed to avoid bucking as the wheelchair started to move forward. The make delay was varied across blocks to have values of 0.04, 0.14, 0.25, and 0.35 s. The order of presentation was counterbalanced.

Samples of the state of the head switch, head position, and wheelchair headrest position were taken every 3.0 ms for a period of 5 s. The latter two variables were measured with a CODA-3 measurement system that optically sampled the location of position markers placed in the middle of the subjects' forehead and on the wheelchair headrest.

Results

With the 0.04 s "make" delay, the subject exhibited a prolonged series of oscillations under instructions to buck deliberately. The rate of oscillation was about 7 Hz. The subject was able to suppress these oscillations when instructed to avoid bucking. With longer "make" delays, the subject exhibited only one or two switch openings per trial when instructed to buck deliberately. The head movement was of greater amplitude than in the 0.04 s condition. These episodes were also eliminated with instructions to avoid bucking.

EXPERIMENT 3

Method

One 33-year-old female with quadriplegia due to brain stem syndrome served as a subject. This individual did not have sufficient control over the muscles of her mouth to use a sip-and-puff control and instead used a head switch (Zygo Tread Switch). The wheelchair had an inherent "make" delay of 0.11 s and an inherent "break" delay of 0.06 s. An experimental time delay ranging from 0.01 s to 0.21 s was added to the "make" delay by means of an electronic timer.

The subject had to drive six feet across a smooth cement surface, cross a piece of thick carpeting which had a 1.5-inch wide by 0.37-inch high board underneath its center, and then continue on for another six feet on the cement surface. The subject then immediately turned the wheelchair around and repeated this process until she had passed over the carpet six times in succession in as continuous a manner as possible. This constituted one trial. There were four experimental conditions corresponding to different "make" and "break" delays (Table 1). With the exception of the added 0.01 s "make" delay, condition D was the same as the subject had used on a daily basis for four years. The subject performed eight trials, two trials with each of the delay conditions. The order of conditions was counterbalanced.

Results

The data consisted of strip chart records indicating when the head switch was open and closed. Based on the results of the previous experiments on deliberate bucking, it was hypothesized that Condition C would result in the least bucking behavior. For the purposes of analysis, bucking was defined as a succession of at least three changes of state of the head switch such that the time interval between successive changes was less than 0.5 s.

Table 1

Condition*	Total No. of Episodes	Median No. of State Changes
A(0.12,0.06)	17	7
B(0.21,0.06)	19	6
C(0.32,0.06)	19	3
D(0.32,0.26)	19	5

* The "make" delay and "break" delay in seconds are shown in parentheses.

As shown in Table 1, the four conditions had approximately equal numbers of episodes of bucking. However, Condition C had significantly fewer state changes per episode as revealed via directional chi-square tests.

DISCUSSION

The present experiments suggest that a time delay of about 0.3 s between head switch closure and motor activation may be helpful in reducing head oscillations. This result is somewhat surprising, in that time delays can cause oscillatory behavior in high gain closed-loop control systems. However, in the present context the delay appears to disrupt a resonant oscillation. The delay may have an unwanted effect of increasing the amplitude of some head movements (Experiment 2). However, this disadvantage was judged to be slight.

Many questions remain to be answered regarding this bucking phenomenon. For example, does this phenomenon occur with continuous analog controls? Lozac'h (2) found it useful to incorporate a 0.1 s time constant in a continuous wheelchair head control to make backing up smoother. A 0.5 s time constant was useful in reducing the effects of unwanted knee movements in a continuous knee control for people with cerebral palsy (3). These manipulations entail smoothing as well as delaying quick changes, however.

The mathematical model of the head-wheelchair coupling needs to be reformulated to reflect the high resonance frequencies revealed in Experiments 1 and 2. The computer simulation assumed that only the head mass was oscillating, and the model generated much lower frequency oscillations. The experimentally observed values of 4 - 7 Hz. suggest that bucking may be a manifestation of a whole-body resonance (4). Nevertheless, the usefulness of a computer simulation in suggesting possible modifications of the wheelchair control system was demonstrated in this study. The authors hope that other investigators will attempt to reproduce the results reported in this paper to provide a more extensive test of this suggested use of a short time delay to retard the bucking phenomenon.

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AN ENERGY-STORAGE DC-DC CONVERTER FOR ELECTRIC WHEELCHAIR DRIVES

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ABSTRACT

Electric wheelchairs are powered by batteries which store a limited amount of energy. Consequently, efficiency converter is of paramount importance. The usual way of obtaining a variable dc voltage is by means of a pulse- width-modulator converter which is extremely efficient, but its waveform has detrimental effects on the lifetime of the battery and motor. In addition, the alternating current components contribute to losses but not to developed torque. A new dc-to-dc converter is presented in this paper which has better efficiency than existing commercial PWM converters. The new converter provides nearly dc output voltage, thus prolonging battery and motor life.

INTRODUCTION

Electric wheelchairs have been available in the market for more than three decades. Physicians recommend the use of manual wheelchairs so that the handicapped can exercise the functional part of his body. But in some cases, the handicapped may not have enough strength to use a manual wheelchair [1] and have to rely on an electric wheelchair.

For most electric wheelchairs, the power is supplied by one or two batteries stored under the seat. Since the amount of power stored in batteries is limited, the efficiency of power supply and of the motors determines the distance the wheelchair can travel without recharging the battery. The power supply for the wheelchair also needs to provide variable output voltage for motor speed control and reversible polarity for the control of the direction of motor. Therefore, the need exists for small, efficient and cost effective variable voltage power supplies for electric wheelchairs.

In this paper, a dc-to-dc converter for electric wheelchairs is presented. The new dc-to-dc converter has better efficiency than some of the existing power supplies tested in the lab. The new converter also provides near dc output voltage and thus prolongs the motor and battery life.

To improve the efficiency of the converter, the designer needs to eliminate any component that consumes power (mainly resistors). Energy storage devices that ideally do not consume power can be utilized in the design. This leaves the designer with switch, capacitor and inductor to work with. Therefore, the natural choice for the converter will be the switching voltage regulator.

The simplest form of switching regulator is shown in Fig. 1. The effective output voltage of this type of converter is the average dc value of output voltage, which is

$$V_o = DV_s \qquad (1)$$

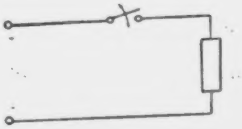

Figure 1. Non-energy Storage Switching Converter

where V_s is the supply voltage and D is the duty ratio i.e., the percentage of the cycle during which the switch remains closed.

The MOSFET bridge circuit shown in Fig. 2 is used in the Alexis wheelchair [2]. This is a slight variation of the converter shown in Fig. 1. By changing D, the speed and the direction of the motor can be controlled. Since energy loss occurs only in the MOSFETs, the converter has very good efficiency. Unfortunately, the pulsating waveform of the output voltage reduces the efficiency of the motor. Other disadvantages of this type of power supply are that the maximum output voltage is always lower than the supply voltage and that the motor and battery lifetime are shortened compared to dc operation [3].

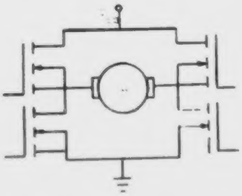

Figure 2. MOSFET Bridge Motor Driver

CONVERTER TOPOLOGY

A modern dc-to-dc converter must be of the energy-storage type in order to produce near dc output and to minimize electromagnetic interference (EMI). There are two basic types of dc to dc converters: buck topology and boost topology, each with its own characteristics, advantages and disadvantages [4]. The buck converter produces severe EMI. The boost converter has considerable output ripple. The boost-buck topology of Fig. 3 (a) eliminates these problems and has a maximum output voltage higher than the supply, the same as the boost converter.

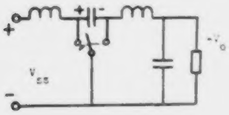

Figure 3(a). Boost-Buck Topology

The output of the boost-buck topology will be:

$$V_o = \frac{D}{(1-D)} \qquad (2)$$

If the inverse polarity at the output can be tolerated, the number of switches can be further reduced as shown in Fig. 3(b). The topology shown in Fig. 3(b) is called Cuk topology [5]. Cuk topology is adopted for the new converter design because it effectively retains the advantages of the boost-buck type while being of simpler construction. Notice that input port and output port can be switched without changing the topology.

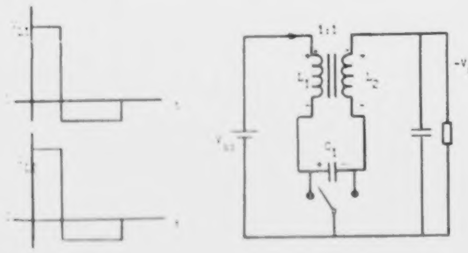

Figure 3(b). Voltage Waveform Across Inductors in Cuk Converter

When used in electric wheelchair, this feature allows regenerataive braking when the wheelchair is going downhill.

Reducing the Output Ripple

As shown in Fig. 3(b), the voltage waveform across L_1 and L_2 are the same. This enables us to couple the two inductors and use one core for both [6]. This results in two energy paths: one through the capacitor, C_1, and the other through the magnetic field via inductive coupling. Coupling the inductors provides something more than just reduction in component count and an alternate energy path. By choosing

$$k = L_M / \sqrt{L_1 L_2} = n = \sqrt{L_1 / L_2} \qquad (3)$$

the output ripple is eliminated [4,6] and the part count is decreased by one output capacitor (no filtering is necessary).

COMPONENT SELECTION

In order to implement the Cuk-topology converter of Fig. 3(b), the selection of magnetic core, inductor design, capacitor type and electronic switch type are critical. A detailed analysis is given in [4].

The best selection for the core would be ferrite. However no commercial ferrite cores are available with the 25A current capacity required by the converter. Consequently, the next best alternative was chosen: Mollypermalloy Powder Cores from Magnetics Inc. The powder core has airgaps distributed along the magnetic path to handle large dc bias currents without saturation. The turn ratio of L_1 and L_2 was chosen to minimize current ripple and optimize converter performance. The capacitor type was chosen based on dielectric material, Q factor, losses and ripple current rating.

For switching selection, bipolar and field-effect transistors were compared, with the results shown in Table I. The MOSFET transistors offer better performance for this application. The following alternatives were tested and evaluated [4]: P-channel and N-channel; N-channel only. It was decided that the N-channel, P-channel combination offered the best performance. The IRF150/IRF9140 were chosen for implementation.

Table I. Comparison of Bipolar Transistor and FET

Parameter	Bipolar	MOSFET
Switching Performance	Temperature Dependent	Temperature independent
Switching Speed	100 - 500nsec	20 - 100 nsec
Minority Carrier Storage	1 - 2 μsec	none
Peak Current Rating	Limited by Gain	Not Gain Limited
Safe Operating Area	$I_{s/b}$ Limited	Power Limited Only
Drive	Current	Voltage
Drive Power	Up to 5W	None*
Reverse Bias	I_{B2} Drive is required	None Required

As mentioned above, to drive the switch, a pulse width modulator is needed. Instead of designing a PWM, we can use a PWM built into a chip. The one used in the design is SG3524. It has on chip voltage regulator, oscillator, error amplifier and comparator. The oscillator frequency is controlled by an external RC. If high output current is desired, a memory drive like the DS0026 can be used. A complete schematic diagram of the converter is shown in Fig. 4. The mechanical switches shown in the figure will be replaced by MOSFET switches for bidirectional operation [4].

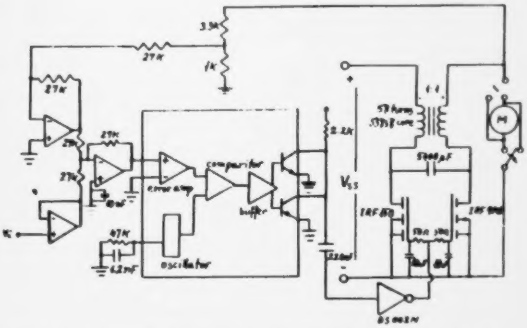

Figure 4. Schematic Diagram of the new Converter

TESTING

The first test consisted in observing the output voltage and load current wave forms during actual motor operation. Both were extremely constant except at the switching instant, where small transients occurred. Next, the efficiency of the converter and of the combination motor-converters were measured using a Magtrol dynamometer and high precision digital power analyzer. The performance was compared with that of a 400 Hz and a 40 KHz Invacare converter. Although the efficiency of the converter is lower than the efficiency of the Invacare converter for output voltages higher than 13V, the combination new-converter-motor has higher efficiency than the two Invacare for all output voltages and loading conditions. In addition, the new converter has a relatively constant efficiency for all output voltage-load combination. Fig. 5 shows the test results for a load torque of 0.6. Notice that the maximum output voltage of the Invacare converters is about 18 volts for a battery voltage of 24.

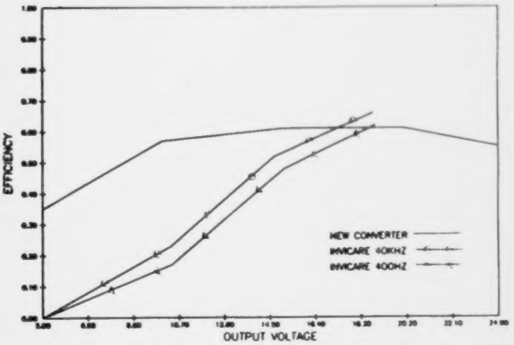

Figure 5. Efficiency of Motor Plus Converter at B=.6 ft.-16-sec

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Improvements and Performance of an Adaptive Battery Monitor

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ABSTRACT

A battery monitor has been developed for the electric wheelchair environment [1]. The monitoring technique used is a combination of open circuit voltage and coulometric (amp-hour counting) measurements. An adaptive feature is incorporated in the monitor enabling it to adjust to different size batteries as well as the effect of aging. A new method of predicting the open circuit voltage requiring less than 7 minutes of no-load period has been implemented. This method employs the slope of the open circuit voltage recovery process to predict the fully stablized open circuit voltage. Field tests have been conducted using the prototype monitor and a commercial battery monitor manufactured by Curtis Instruments, Inc. The adaptive monitor performed comparably to the commercial monitor on level surfaces, and showed significantly better accuracy on hilly roads. The monitor has been found to be applicable to all lead-acid type batteries, including gell cells and regular wet cells.

INTRODUCTION

The state of charge of the batteries used in electric wheelchairs is essential for efficient and cost-effective operation. Knowing the state of charge of the batteries in an electric wheelchair is equivalent to knowing the amount of fuel in the fuel tank of an automobile. Therefore, a battery monitor for an electric wheelchair or other battery-powered electric vehicles is comparable to a fuel guage in an automobile.

An accurate monitor can serve several purposes. First, it can warn a wheelchair user against dangerously low levels of charge. Low charge conditions not only create the situation of possible stranding but also can shorten the life of the batteries, can damage the cells, and can inhibit the ability of the batteries to be charged to the maximum capacity. Second, it enables a user to utilize the batteries to a maximim degree without the total loss of charge. A survey performed bt Curtis Instruments indicated that almost 50% of wheelchair users experienced a stranding, and consequently used an extremely conservative discharging policy. However, unnecessary charge cycles due to this conservatism resulted in frequent overcharging, which also has damaging effect to the batteries [2].

A battery monitor which displays the state of charge of the batteries has been developed and tested. The technique used is a combination of the open circuit voltage measurement and coulometric measurement (amp-hour counting). A technique has been developed to predict the open circuit voltage within seven minutes into the recovery process. An adaptive feature is included which enables the monitor to adjust to different batteries as well as the effect of aging.

The basic operation and implementation of the prototype is found in [1]. This paper describes an improved method of predicting the open circuit voltage and results of several field tests using the prototype and a monitor manufactured by Curtis Instruments.

DEFINITION OF CAPACITY

There are several factors that make a battery monitor differ from a simple fuel guage. For an automobile, performance does not depend on the amount of fuel remaining, and the average rate of fuel comsumption has no effect on the total amount of fuel available. Also, there is a clear definition of "empty", where the automobile will stop running. For the battery, the operating voltage level decreases as the level of charge decreases and the rate of discharge has a significant effect on the available capacity. Also, there is no clear definition of the point at which a battery is completely depleted of charge. For these reasons, it becomes necessary to define the "capacity" of a battery.

There are three ways to define capacity: 1) theoretical capacity; 2) usable capacity; and 3) state of charge. The theoretical capacity is the maximum output obtainable from a battery. This value can be computed from the amount of active material within a cell, assuming the complete consumption of the active material present [3]. This theoretical capacity is not available for several reasons. First, the slow diffusion process of the electrolyte limits the amount of acid to reach the plates making the battery unusable before the electrolyte is depleted. Also, the internal resistance of a cell increases as the level of charge decreases.

The usable capacity defines the number of amp-hours available to the load at a certain discharge rate. In order to obtain the usable capacity, it is necessary to select a cut-off voltage, or final voltage, which is the lowest operating voltage of a cell at which the cell is considered depleted. This cut-off voltage is usually defined as the "knee" of the loaded voltage discharge curve where the terminal voltage drops rapidly. The cell may be discharged beyond this point but only a small percentage of the theoretical capacity can be obtained after the knee of the curve. This cut-off voltage varies with dicharge rate and the usable capacity is a function of discharge rate, temperature and battery size. Also, it should be noted that the usable capacity does not take into account the recuperation rate. With intermittent rest periods between discharge, more usable capacity can be obtained from a battery. Although the usable capacity is a function of a number of parameters, it is used as a practical alternative for the theoretical capacity and most commercially available battery monitors use this unit of measure.

State of charge differs from the usable capacity in the sense that it indicates the "state" a cell is in rather than defining the number of amp-hours available from a cell. It is, therefore, an indication of the concentration of the acid in the electrolyte. It should be noted that using the state of charge as an indicator implies nothing about the usable capacity. Usable capacity can be obtained from the measurements taken with the new monitoring technique.

ADAPTIVE MONITORING TECHNIQUE

The monitoring technique used is a combination of open circuit voltage and coulometric measurement techniques. By combining the two techniques, it is possible to account for the weaknesses of both techniques. Coulometric measurement is the process of summing the amount of capacity taken out of (or put into) a battery in terms of amp-hours. It is used in short-term operations, where the accumulation of error will be negligible. The error that is accumulated can be eliminated when an open circuit voltage reading is taken. The open circuit voltage measurement is taken only after the battery has been *at rest* for a sufficient period of time. The coulometric measurement technique helps accomodate the lengthy stablization period associated with the open circuit voltage measurement process.

In addition, the technique includes an adaptive feature which modifies the model based on the battery size and age as determined during operation. It should be noted that this technique has been limited to lead-acid type batteries because of the unique open circuit voltage/specific gravity relation that exist for lead-acid batteries.

Prediction of open circuit voltage

The rest period required to obtain an accurate measurement of the open circuit voltage can be extremely long. It was therefore found necessary to predict, in some fashion, the open circuit voltage before full stabilization had taken place. In the initial algorithm, a rest period of thirty minutes was used. The assumption for this technique was that an identical set of voltage recovery curves existed regardless of the state of charge or the discharge rate prior to the recovery process. Mathematically, the technique can be represented as

$$V_{oc} = V_{tr} + K_v \tag{1}$$

where V_{oc} is the fully stablized open circuit voltage. V_{tr} is the voltage at t_r, t_r is the length of the arbitrary rest period, and K_v is the constant difference between V_{oc} and V_{tr} for the battery.

The above technique worked well for a specific battery but the constant K_v varied significantly with different batteries. An alternate method was developed to compensate for this defficiency. Consider the recovery curve of Figure 1. The curve can be approximated by two asymtotes if plotted on semi-log scale. A new variable X was introduced in place of t (time) in order to obtain a linear equation. The relation is therefore:

$$t = 10^X \tag{2}$$

From Figure 1., X_p is the value of X at the intersection of two asymtotes. Therefore,

$$V_{oc} = M^* X_p + V_o \tag{3}$$

where M is the slope of the first asymtote, X_p is the value of X at the intersection, and V_o is the voltage at t=1 minute.

Data was collected from several different batteries at various levels of discharge and state of charge. A average value of 1.64 resulted for X_p with a standard deviation of only 0.2. The following equation to predict the open circuit voltage resulted:

$$V_{oc} = 1.64^* M + V_0 \tag{4}$$

An analysis was conducted to determine the amount of error that would result from the use of this equation. The error was remarkably small, with an average state of charge error of 1.6%.

The values of time which were decided to be the most appropriate to be used to determine the slope of the recovery curve were 1 minute and 6.6 minutes after the removal of the load. These values were chosen because of the linearity of the curve between those points and the desire that the needed multiplication in the computer to be a simple shift (multiplication by a power of 2).

Coulometric measurement model

During charge or discharge cycles, coulometric measurement is used to continuously update the remaining capacity. A relationship between capacity removed per sample and the load current can be derived for a battery of a given size and a given age. If the load is fairly consistent, the relationship can be assumed to be linear.

To compensate for changing average loads and different size batteries, a algorithm was developed that would "learn" the characteristics of the current battery. The algorithm compares the predictions of the remaining capacity by the open circuit voltage measurement and the coulometric measurements and adjusts the coulometric model to fit the result of the open circuit voltage measurement. Implementation of this technique is illustrated in Figure 2. The error correction factor (ECF) is defined as illustrated on the curve and can be shown to be:

$$ECF = \frac{(C_{ocv} - C_{cm})}{C_t} \tag{5}$$

where C_{ocv} is the remaining capacity predicted by the open circuit voltage, C_{cm} is the remaining capacity predicted by the coulometric measurement, and C_t is the total capacity removed during the total discharge period from the last update. The ECF is reevaluated each time an open circuit

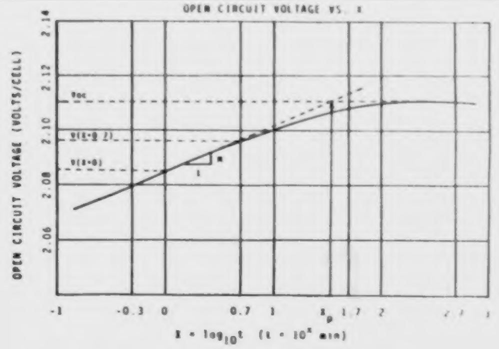

Figure 1. Model for OCV Prediction

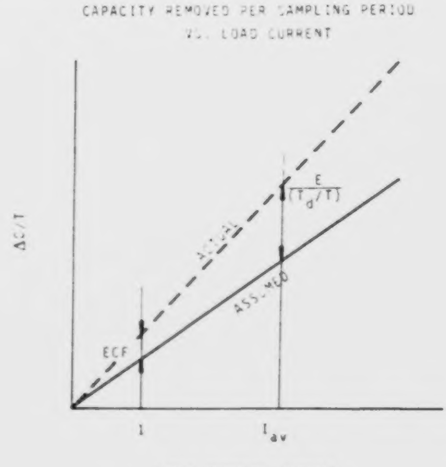

Figure 2. Error Correction Process

voltage measurement is made to update the remaining capacity. The value of ECF is added to the base coulometric model.

FIELD TEST RESULTS

The prototype monitor was mounted on a "Rolls" electric wheelchair by Invacare for field test purposes. The wheelchair was equipped with two 1/5 horsepower motors driving the rear wheels through direct gearing with a 15:1 reduction ratio. The chair was equipped with a two-speed controller made by General Teleoperators, Inc. The Chair was powered by two 40 amp-hour Donley 22NFD deep-discharge batteries.

A battery monitor marketed by Curtis Instruments was also attached to the wheelchair for comparison. The Curtis Fuel Guage uses the loaded voltage measurement scheme to determine the state of charge.

Two routes were chosen in evaluating the monitors. Slope of the routes were estimated and distances were measured using an automobile odometer, taking an average of several readings. The first route was a level surface with a lap distance of 0.24 km. Inclines were small. The wheelchair was operated at full speed and stops of less than 30 seconds were made after each lap in order to record the state of charge. The batteries were rested at roughly 20% decrements of the state of charge. The duration of the rest period varied from one hour to overnight.

The second route was chosen to evaluate the monitors in a situation where the load varied greatly. The lap distance of this route was 4 km. with slopes as steep as 20 degrees on some portions. Again, the batteries were rested at varies periods to obtain state of charge measurements. The duration of each rest period varied from one hour to overnight.

Specific gravity measurements were made at each rest period and used as the reference for the evaluation. Figure 3 shows the performance of the monitors using the first route with Figure 4 representing the results of the monitors on the sloped surface. Both monitors performed well on the level surface with a slight tendency to overpredict when the batterues were near full charge and to underpredict at low levels of remaining capacity. The adaptive monitor continued to perform well on the sloped surface. However, disadvantages of the technique used in the Curtis Fuel Guage became apparent in the sloped tests. The condition of higher load current (and consequently lower operating voltage) resulted in a state of charge underprediction by as much as 30%.

CONCLUSIONS

It has been successfully shown that the technique outlined in this paper and in [1] is implementable and an accurate method of monitoring the state of charge of lead-acid batteries. The performance of the technique has been shown to be better than one of the more popular monitors available.

Two areas that need additional investigation before the device can be incorporated into a design are the effects of the charging cycle and power consumption of the monitor. Power consumption must be minimized during the rest periods and techniques should be used to "shut down" the system when not in use.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the University of Virginia Rehabilitaion Center and the National Institute for Handicapped Research.

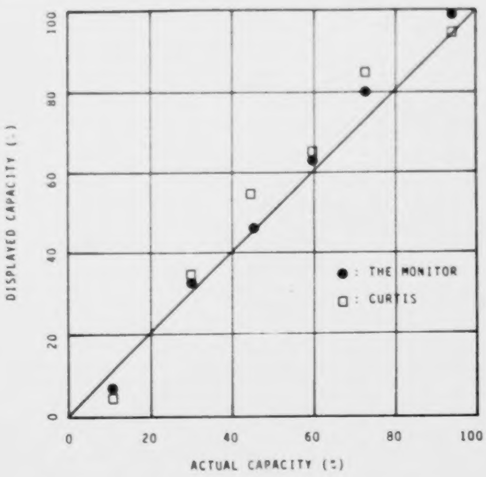

Figure 3. Field Test Results from Level Surface Route

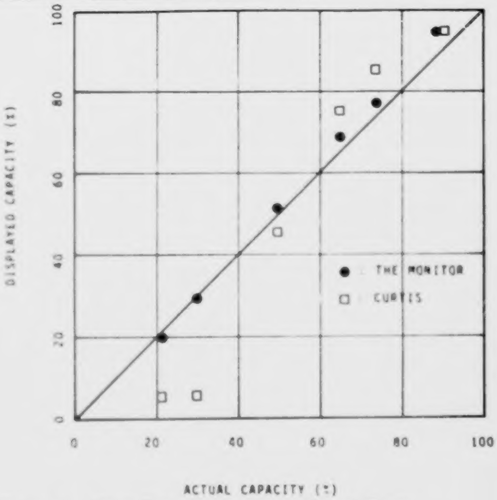

Figure 4. Field Test Results from Sloped Route

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A NEW BATTERY WITH VERY LONG LIFE FOR ELECTRIC WHEELCHAIRS

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ABSTRACT

The economic and performance characteristics of the tubular positive plate lead acid battery are reported based on a comparison with the flat plate lead acid batteries which are currently used in electric wheelchairs in the USA. The main advantage of the tubular positive plate design is found to be its very long cycle life under deep discharge conditions. It is estimated that tubular positive plate batteries would extend the replacement period from about one year to over four years for typical wheelchair use, with a potential saving in the USA of $4.86 million/year!

INTRODUCTION

The lead acid battery used in electric wheelchairs operates by an electrochemical reaction between a negative voltage plate of spongy lead, a positive voltage plate of lead dioxide, and a dilute solution of sulfuric acid known as the electrolyte. Each pair of plates, called a cell, produces an open circuit voltage of about 2.1 volts. The amount of electrical energy that can be stored in each cell depends on the quantity of active spongy lead, lead dioxide, and sulfuric acid.

This report concerns the characteristics of deep cycle, lead acid batteries of the tubular positive plate design. These electric wheelchair batteries are now available in Europe, and have several advantages over the standard flat plate design currently available in the USA.

BATTERY DESIGN

Figure 1 shows the elements of a typical tubular positive plate lead acid battery. The active lead dioxide of the positive plate is contained in porous tubes of terylene, glass fiber, or perforated plastic, and surrounds a lead rod conductor running down the center of the tube. The negative flat plate is a lead grid design with pasted spongy lead in the grids. Porous separators are placed between the plates, and each cell is contained in a polypropylene case. The conventional flat plate battery is similar except that the positive plate is built like the negative plate shown in Figure 1, using lead dioxide.

During discharge of the battery, the lead dioxide reacts with the sulfuric acid and changes to lead sulfate. When the battery is recharged, the lead sulfate is converted back to lead dioxide plus sulfate ions, which diffuse into the electrolyte. This process causes the active solid material of the positive plate to change density which in turn causes shedding of the active material and reduces the capacity of the plate. The tubular sleeve surrounding the active lead dioxide of the tubular positive plate maintains the integrity of the active material and keeps it from shedding, leading to a substantially longer cycle lifetime. The shedding effects are not severe at the negative plate, so no special precautions are needed. In recent years, flat positive plates have been improved by adding mummy-like plate insulation which tends to protect the active material from shedding. However, even with this improvement, the tubular positive plate is still able to outperform flat plate designs. A comparative study of cycle lifetime will be presented in the discussion section of this paper.

There is another significant difference that has been noted between tubular positive plate batteries and flat plate batteries of the same rated capacity (5 hour discharge rate at 30°C). Users of the Exide Corporation tubular positive plate industrial batteries in coal mine electric vehicles said, "Exide is a hot battery" (1). The Exide battery performed 25% to 30% more work than similar flat plate batteries when compared at intermittent, high rate discharges, similar to industrial truck duty cycles. Exide (1) states, "this effect is simply basic engineering; it is the greater plate surface area and better circulation of electrolyte." The key reason why users find these batteries "hot" is due to the fact that under heavy load conditions the vehicle still moves fast. This means the terminal voltage of the tubular positive plate batteries is not depressed as much under load. Since voltage and current are related to the power that is delivered, it will be shown in the next section that there is a significant difference between tubular and flat positive plate batteries when compared on a power versus time of discharge basis. This effect is important to electric wheelchair users as it will cause the wheelchairs to perform in a "hot" manner under heavy load.

TEST METHODS AND RESULTS

The tests that were carried out on tubular and flat plate batteries at the UVA REC involved capacity measurements for a single discharge. Capacity tests are related to the distance an electric wheelchair will travel before the battery must be recharged. The next most interesting test relates to lifetime cycles. Lifetime cycle tests will give the number of days a battery can be used in an electric wheelchair before it must be replaced because it fails to perform satisfactorily.

Lifetime cycle tests are very time consuming, and were not done in our laboratory, but data from a recent report is presented in the discussion section.

Battery capacity is a measure of the usable energy that a battery can deliver at a specified discharge current at 30°C, until a cutoff voltage of 21 volts for a 24 volt battery is reached after a full charge. A battery's capacity depends on plate geometry, temperature, rate of discharge, and previous discharge history. When the battery is discharged to the cutoff voltage, it is said to experience 100% depth of discharge (DOD). This method is used to test batteries at the REC, although it has been determined that the lifetime cycles of a battery are much longer at lower depths of discharge. The latter result is the basis for the recommendation that an electric wheelchair user should recharge his battery every night. On an average, this leads to a lower depth of discharge and a longer battery lifetime cycles.

Figure 2 shows the results of capacity tests at room temperature (80°F) for an Exide tubular positive plate, 12 volt battery. Data is given for steady discharge currents of 5, 10, 30, and 50 amperes as power (watts) versus time of discharge to the cutoff voltage. In addition, capacity during discharge for simulated indoor and outdoor electric wheelchair driving cycles are shown. The latter tests give a measure of the time the wheelchair will operate before the battery must be recharged. The duty cycle used is described in Ref. 2.

Data taken from an earlier report on flat plate battery studies for wheelchairs by Kauzlarich et al. (2), is also plotted as a dashed line. A comparison of the capacity curves for tubular and flat plate batteries, having the same 20 hour discharge capacity, shows that the tubular plate design has a greater capacity than the flat plate design in terms of energy (watt-hours). The data in Figure 2 shows that at the 1 hour discharge point, the tubular plate design will deliver 23% more energy than the flat plate design. As discussed earlier, this effect is due to greater exposed plate surface area and better circulation of electrolyte. This is what makes the user call the tubular plate battery a "hot" battery.

LIFETIME CYCLES

In a recently issued report by Peterson (3), several batteries were tested for lifetime cycle performance. The results of that study are shown in Fiqure 3. The test program involved discharging the battery at the 5 hour discharge rate (about 10 amperes), at 20°C, until the battery was discharged to 80% depth of discharge, and then it was recharged. Each cycle of discharge/charge is counted until the 5 hour discharge rate battery capacity falls to less than 80% of the initial rated capacity. The report described tests of lifetime cycles at 25% depth of discharge and lifetime cycles under simulated wheelchair duty cycle performance, but this will not be reported here.

The batteries tested in Figure 3 are grouped by type, with automotive SLI (starting, lighting, and ignition) shown as the lowest in lifetime performance of the several groups. A calculation of first cost divided by lifetime cycles will show SLI batteries to have the greatest cost per cycle, even though the first cost of the battery is lower than the other batteries. This was also shown to be true in an addendum to the article by Kauzlarich et al. (4).

The cost of two batteries for electric wheelchair use, based on prices in the 1987 Sears Roebuck catalog and cost experience at our REC are shown in Table 1. Estimates of lifetime cycles of discharge/charge (approximately days of use) are listed next. Typical wheelchair lifetime cycles are approximately 3 times the maximum test data in any group shown in Figure 3. The resulting estimate of operating cost in $/cycle in Table 1 clearly shows the economic advantage for using tubular positive plate lead acid batteries.

Table 1: Operating Cost of Battery Groups

	Cost, 24 volts	Life Cycles	$/cycle
Automotive	$108	100	1.08
Deep Cycle			
Liquid electrolyte	$120	400	.30
Gelled electrolyte*	$170	290	.58
Starved electrolyte*	$262	480	.55
Tubular pos. plate	$164	1200	.14

*Maintenance free

DISCUSSION

The most obvious result of the data presented in this paper is that the operating cost of an electric wheelchair can be significantly reduced if tubular positive plate batteries, sized to fit a standard wheelchair battery box, were to become available in the USA. It is estimated that at least 60,000 electric wheelchairs must replace both 12 volt batteries each year at a cost of about 60,000X$120=$7.2 million per year. Tubular positive plate batteries last up to 4 times longer than flat plate deep cycle batteries (See Figure 3), but cost about 30% more than deep cycle batteries. Thus, using tubular positive plate batteries the cost is 60,000X$120X1.3=$9.36 million per 4 years, or $2.34 million per year. Thus, it is estimated that using tubular positive plate batteries in place of flat plate batteries in electric wheelchairs would save the consumer on the order of $4.86 million per year!

Although tubular positive plate batteries are available in Europe, the cost of importing them to the USA is prohibitive. So far, American manufacturers have shown very little interest in producing tubular positive plate batteries, since the wheelchair market is relatively small.

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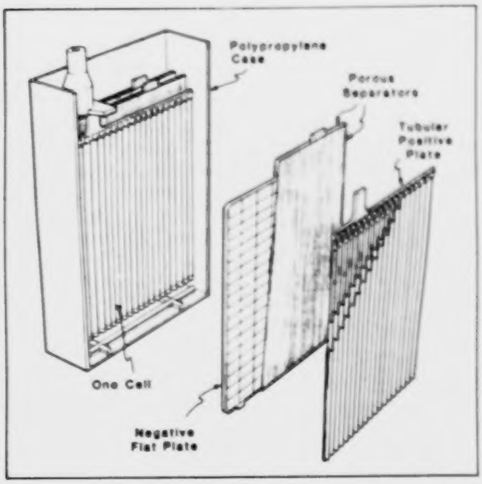

Figure 1. Tubular Positive Plate Lead Acid Battery

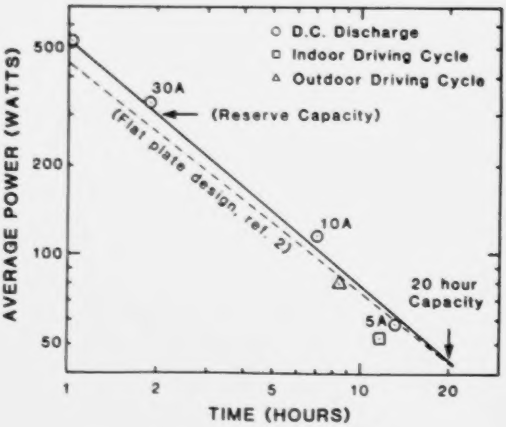

Figure 2. Exide Tubular Solar Type 6E31-5

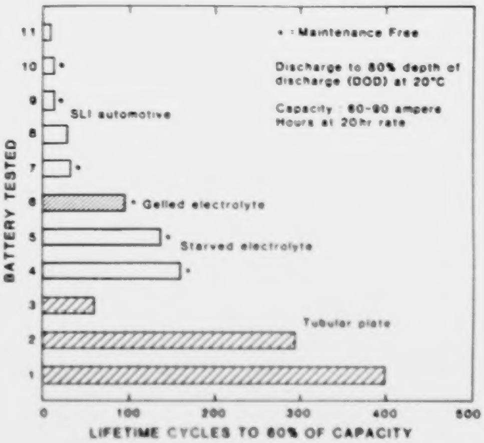

Figure 3. Lifetime Cycles Battery Test, After Peterson (3)

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THE APPLICATION OF FAULT TOLERANCE TO MICROPROCESSOR-BASED WHEELCHAIR CONTROL SYSTEMS

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ABSTRACT

Microprocessors are being used in an increasing number of applications, including electric wheelchair control systems. In the electric wheelchair application, as in many others, three primary attributes desired for the system include: (1) an ability to operate for as long as possible without failing, (2) an ability to be quickly repaired such that any period of inoperability is minimized, and (3) an ability to prevent any failed component, such as the microprocessor, from causing uncontrollable or unpredictable wheelchair responses. *Reliability*, *availability*, and *safety* are three quantitative measures which may be used to evaluate the effectiveness of a particular system in achieving the three desired attributes. This paper presents a fault-tolerant, microprocessor-based controller developed by the authors for the electric wheelchair. Analysis results are also presented to demonstrate the improvements in reliability, availability, and safety attained by the fault-tolerant controller in comparison to a controller without fault tolerance.

INTRODUCTION

With the many potential advantages offered by the microprocessor [1-2], it is disappointing that electric wheelchairs are not being equipped with these devices. An impediment to using microprocessors on wheelchairs is the vulnerability of the resulting systems to both permanent and transient failures. For example, microprocessors tend to be sensitive to power supply fluctuations that could result in the wheelchair user losing control of the chair. Unlike analog circuits, the microprocessor does not possess an inherent ability to recover from transient disturbances; microprocessor-based systems must be *designed* to provide forms of self-recovery. Erroneous actions by the controller could easily result in physical harm to the handicapped user because the user has limited capabilities to use in recovering from anomalous conditions that occur in the wheelchair system.

The focus of this paper is on the design of a fault-tolerant, microprocessor-based controller for the electric wheelchair. A fault-tolerant controller is one that possesses the ability to continue to operate correctly after faults have occurred [4]. Several candidate architectures for the controller have been developed and analyzed. Using commercially-available hardware, a flexible, laboratory model has been constructed to implement several of the proposed architectures and to investigate the effectiveness of the fault detection techniques, reconfiguration algorithms, and graceful degradation approaches.

A FAULT-TOLERANT CONTROLLER

The architecture of the fault-tolerant controller, as it was implemented, is shown in Figure 1 and consists of two Intel 8088 processors and a shared memory. The shared memory is used as a means of communicating between the two processors and consists of a 16K random-access memory (RAM). Each processor's local memory has both RAM and programmable read-only memory (PROM). Local memory is used for program storage and the temporary storage of data. The processors also have a local input/output (I/O) bus to which devices such as analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) may be connected. Each processor operates independently using its own clock and its own PROM for program storage and execution.

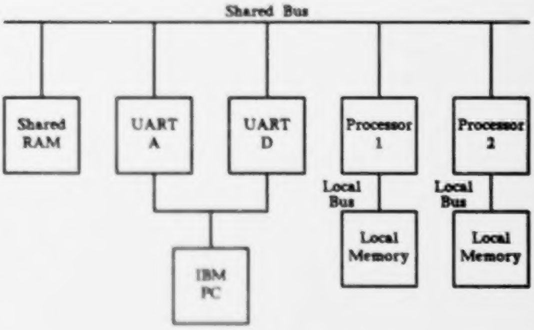

Figure 1: The experimental, fault-tolerant system

The present system allows two types of fault tolerance techniques to be implemented; reconfigurable duplication and standby sparing [4]. In reconfigurable duplication both processors perform the same calculations, and the results are compared for the purpose of fault detection. Each processor also performs self-test functions in an attempt to specifically identify a failed processor, if one exists. If a failed processor is identified, the remaining processor will continue to perform the operations of the system. During initialization, one processor is specified as the master which provides all control commands to the wheelchair's motors. The second processor (the slave) performs the same calculations for comparison purposes and is available to become master in the event of a failure.

In standby sparing, one processor (the master processor) performs all of the calculations, and the second processor (the slave) acts as a spare. The slave processor is only used if the master processor fails and the failure is detected and located. Standby sparing does not provide for comparing the results calculated by the two processors, but depends entirely upon other means for fault detection.

Each processor in both reconfigurable duplication and standby sparing executes various self-test functions that provide fault detection capabilities. For example, each processor executes a test of both the shared memory and the processor's local memory by writing patterns of alternating 1s and 0s to the memories and then reading those patterns for verification. Each processor also performs certain logical and arithmetic functions and compares the results with known values stored in PROM. Once a processor has performed each of its self-test functions, the processor must report the results of those tests to a specified location in shared memory. The master processor will read the results from shared memory and clear them such that the processors must periodically replace the results. The failure of a processor to report on its *health* is considered an indication that the processor is faulty.

The experimental system has demonstrated the effectiveness of the fault detection techniques and the reconfiguration strategies. For example, it is possible to simulate the effects of the failure of one processor's analog-to-digital converter by providing erroneous velocity feedback signals to one of the 8088 processors and the correct signals to the other. The self-test features of the system recognize the faulty condition and remove the affected processor from the system. The remaining fault-free processor continues the execution of the tasks necessary to keep the system running.

CONTROLLER ANALYSIS

The architecture described in the previous section has been analyzed to predict the reliability, availability, and safety. Reliability is simply the probability that the system will function correctly throughout the interval of time $[t_0,t]$ given that it was functioning correctly at time t_0 [4]. Reliability is important in the wheelchair application because it is a function of the expected time that the wheelchair can operate properly without experiencing a malfunction.

Availability is the probability that the system is ready to perform its operations at the instant of time t [4]. Availability accounts for the repair process and is a measure of the percentage of time that the wheelchair is operational. If the wheelchair is time consuming to repair or fails frequently, the fraction of time that the chair is inoperable will be large, and the availability will be low. However, if the wheelchair fails infrequently or is very easy to repair, the chair will have a high availability. Availability approaches a steady-state value that depends on the average rate of failure and the average rate of repair.

Finally, safety is the probability that the system will either perform correctly or will fail in a completely safe manner [4]. Safety is extremely important in numerous applications, particularly the electric wheelchair, and is a measure of the capability of the system to successfully shut down in the event of a failure that can not be tolerated. For example, if the controller uses a single processor and that processor fails, one would like for the system to simply turn itself off instead of performing some unpredictable action.

As an initial comparison, assume the fault coverage provided by the comparison process is perfect, and the self-diagnostics fault coverage is 0.95. Figure 2 compares the reliability of reconfigurable duplication, standby sparing, and simplex for the specified coverage factors and as a function of λt where λ is the failure rate of a processor with local memory and t is time. At the reasonably high fault coverage value used, the reliability of standby sparing and reconfigurable duplication is very similar. The value of the fault coverage factor, however, does have a significant impact on the reliability of the system [3].

The significance of the results shown in Figure 2 can be illustrated by considering a particular value of λ and t. Assume that the failure rate, λ, is 0.001 failures per hour. If $\lambda=0.001$ then the point in Figure 2 where $\lambda t=1.0$ corresponds to 1,000 hours which is slightly more than one month of continuous operation. The results shown in Figure 2 indicate that the simplex system has a reliability of approximately 0.36 at 1,000 hours. Both of the fault tolerance techniques, however, increase the reliability to more than 0.75, an improvement of more than 100%. Clearly, it may be required to increase the reliability even further, and future work will investigate means of accomplishing such increases. The important point of the preliminary results is the relative difference between the reliability of the simplex system and that of the candidate fault-tolerant systems.

Figure 3 shows the availability of the system when the average repair time is 30 days (not unnecessarily large in the wheelchair application). With the 30 day repair time, a 30% improvement in availability is achieved using the fault-tolerant systems. The steady-state availability of the fault-tolerant architectures is approximately 0.8, implying that the system would, on the average, be operational 80% of the time. The

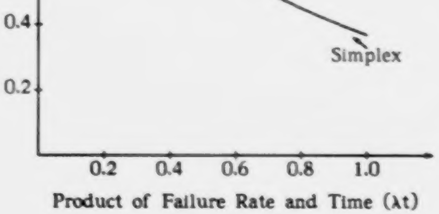

Figure 2: Reliability versus λt

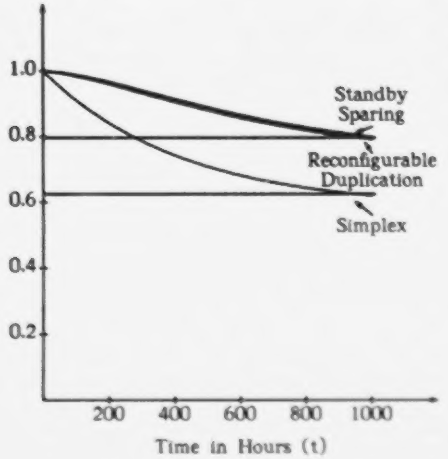

Figure 3: Availability versus time (30 day repair time)

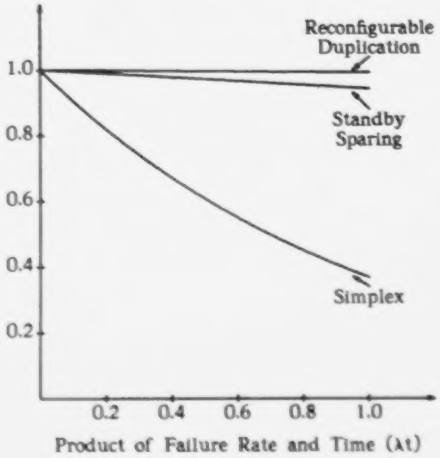

Figure 4: Safety versus λt for the candidate approaches

simplex system, however, would be operational only about 62% of the time.

The final comparison is the safety of the system. Figure 4 compares the safety of reconfigurable duplication, standby sparing, and simplex for perfect comparison coverage and for a self-diagnostics coverage factor of 0.95. As can be seen, reconfigurable duplication achieves a higher safety than standby sparing. Both architectures incorporating fault detection and fault tolerance perform significantly better than the simplex approach. Even though standby sparing achieves a higher reliability and availability than reconfigurable duplication, the latter may be preferable for the electric wheelchair application because of the improved safety that can be obtained. As demonstrated in the paper by Johnson and Aylor [3], the differences between standby sparing and reconfigurable duplication become more pronounced as the coverage provided by the self-diagnostics decreases.

CONCLUSIONS

The research presented in this paper applies fault detection and fault tolerance techniques to the design of a safe, reliable, and highly-available electric wheelchair. The techniques have been demonstrated in an experimental system designed and implemented in the laboratory. Future efforts will focus on installing the prototype system on an electric wheelchair and performing an extensive evaluation of the concepts.

ACKNOWLEDGEMENTS

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ANALYSIS OF PARAMETERS RELATED TO THE DIRECTIONAL STABILITY OF REAR CASTER WHEELCHAIRS

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ABSTRACT:

This paper discusses the fundamental nature of the directional control problem associated with rear caster wheelchairs. The results of an experimental study to determine the nature of the ground forces that act on a wheelchair tire are presented. A description is given of a computer program which simulates simple wheelchair motion. This program, along with the experimental data for tire forces, is intended to give an understanding of the parameters related to the ease of handling of rear caster wheelchairs.

INTRODUCTION:

The problem of controlling an unstable vehicle is not a recent development. For example, it has been known for some time that aircraft equipped with a castered tailwheel experience steering difficulty while taxiing. These planes require tail rudder control and wheel braking in order to maintain a straight path. Wheelchairs that have their pivoting caster wheels in the rear experience a very similar problem.

BACKGROUND:

Aside from the gravitational force, the only forces that act on a moving wheelchair occur at the tire-road interface. For this reason, it is necessary to consider the forces that may act on a rolling tire. These are shown in Figure 1.

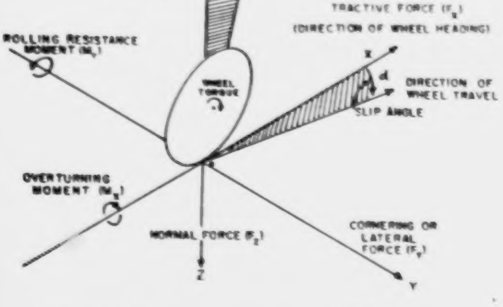
SELF ALIGNING MOMENT (M_z)
γ
CAMBER ANGLE
TRACTIVE FORCE (F_x)
(DIRECTION OF WHEEL HEADING)
ROLLING RESISTANCE MOMENT (M_y)
X
α
WHEEL TORQUE
DIRECTION OF WHEEL TRAVEL
SLIP ANGLE
OVERTURNING MOMENT (M_x)
NORMAL FORCE (F_z)
Z
CORNERING OR LATERAL FORCE (F_y)
Y

Figure 1 Forces on a Rolling Tire

The tire axis system shown is the same as that which is recommended and used by the Society of Automotive Engineers. This system is described by Wong [1].

First, notice the two important angles associated with the rolling tire. These are the camber angle (γ) and the slip angle (α). The camber angle is the angle between the wheel plane and the plane formed by the X and Z axes. This angle may be zero, but is often present because many wheelchair users adjust their tires inward in order to obtain a firm and comfortable grip. The slip angle is the angle between the wheel plane's heading and the actual direction of travel. A slip angle results whenever the wheel has a nonzero velocity component along the Y axis.

Note that the term "slip angle" is not meant to suggest that the wheel is slipping or sliding with respect to the ground. All tires have elastic properties which allow small velocities perpendicular to the wheel heading without any sliding.

There are three forces that act on a rolling tire from the ground:

(1) Fx is the longitudinal force which acts along the direction of the wheel's heading. This force is often called the tractive force. Wheel torques are converted into a propelling tractive force through friction between the tire and the ground. In addition, some tractive force is always necessary in order to overcome a wheel's natural rolling resistance.

(2) Fy is the lateral force and it acts at a right angle with respect to the wheel heading. If the slip angle is not zero, an elastic tire deforms slightly as it is forced to roll along an unnatural path. This deformation results in the lateral force between the tire and the ground. The lateral force resists the tendency for sliding of the wheel, and it always acts in a direction which is opposite the Y axis velocity component. When no camber angle is present, the lateral force is due solely to the presence of the slip angle, and it is often referred to as the "cornering force". This term arises from the fact that some lateral force is always required for any vehicle to change direction or negotiate a turn.

(3) Fz acts in the negative z direction or normal to the contact point with the ground. A vehicle's weight is supported by the sum total of the normal forces acting on each wheel.

Because the ground contact point is generally not directly at the origin of the axis system as shown in Figure 1, the three forces just described create three additional moments that act on the rolling tire. These are shown in the figure, but because their magnitude is usually quite small their effects can be ignored for a first order analysis of wheelchair motion.

IMPLICATIONS FOR WHEELCHAIRS:

Whenever a wheelchair is displaced from the user's desired line of motion by a disturbance such as a bump in the road, lateral road forces develop that act on the tires and produce a twisting moment about the center of gravity. This twisting is due to the cornering force Fy as shown in Figure 2.

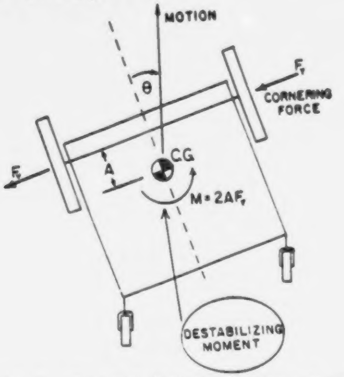

Figure 2 Destabilizing Moment for a Rear Caster Wheelchair

In the case of a rear caster wheelchair, the cornering force produces a twisting or destabilizing moment (M) that tends to rotate the wheelchair even further away from the desired directional heading. The magnitude of this moment is greater for chairs that have a large distance (A) between the chair axle and the chair center of gravity (C.G.). Because of this tendency to drift away from a desired course of motion, rear caster wheelchairs are said to be directionally unstable. It should be noted that in the case of conventional front caster wheelchairs the cornering force has a stabilizing effect.

Due to the fact that the cornering force is primarily responsible for the instability of rear caster wheelchairs, a knowledge of the factors which affect its magnitude is desirable.

RESULTS OF WHEELCHAIR TIRE TESTS:

Several different wheelchair tires were examined using a test cart and a treadmill. A load cell mounted alongside the treadmill was used to measure the cornering force Fy exerted on a fixed wheel which was turned to some known slip angle with respect to the belt motion.

Figure 3 illustrates a typical plot of cornering force as a function of slip angle for a single Everest and Jennings solid rubber tire.

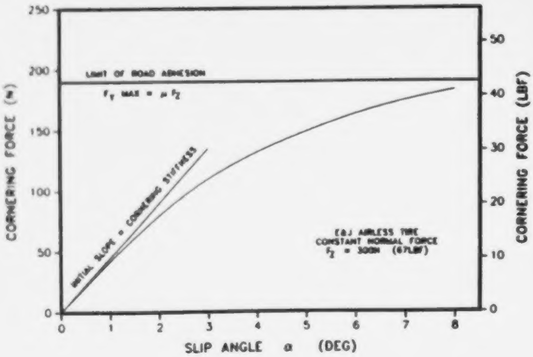

Figure 3 Typical Cornering Force Curve

For small angles of side slip, the cornering force increases linearly with an increase in slip angle. For slip angles larger than about three degrees the cornering force begins to increase at a lower rate, and it reaches a maximum value when the tire begins to slide laterally. At the point where sliding begins, the peak cornering force is determined by the product (μ) x (Fz), where (μ) is referred to as the coefficient of road adhesion [2].

A common basis for comparing different tires is provided by the parameter "cornering stiffness", which is defined as the initial slope in the linear region of the cornering force versus slip angle curve. Smaller cornering stiffness values correspond to lower cornering forces for a given slip angle, and thus in the case of rear caster wheelchairs, will also correspond to less directional instability.

Tests on several tire types under varying conditions have led to the following additional conclusions regarding cornering forces and wheelchair tires:

(1) As expected, increasing the normal force Fz on the tire results in an increase in the cornering force Fy for a given slip angle. However, the relationship between cornering force and vertical load is nonlinear.

(2) Cornering force is almost entirely independent of inflation pressure and forward speed. Varying either of these parameters results in nearly undetectable changes in the shape of a particular tire's cornering force curve.

(3) Cornering stiffness is found to depend quite heavily upon choice of tire. This suggests the possibility of designing or selecting tires to optimize the initial slope of the cornering force curve as a means of reducing instability. The term optimize, rather than minimize, is used because some lateral force is desirable. Also, while attempting to reduce cornering stiffness, other factors such as rolling resistance and tire wear should be considered.

(4) The presence of a camber angle tends to slightly decrease or increase the magnitude of the lateral force, depending on whether or not the camber inclination is toward or away from the direction of lateral wheel motion.

SIMULATION MODEL:

A five degree of freedom mathematical model for simulating wheelchair motion has been developed as a means of examining the parameters that affect handling and stability. The equations of motion that govern a rolling wheelchair are fairly cumbersome and will not be presented here.

To begin the process of simulating the motion of a rear caster wheelchair, all variables of interest to the stability problem are initially defined. These include obvious parameters such as geometric dimensions, as well as minor variables of interest such as the amount of friction present at the caster pivot points. Experimental data is used to develop a family of empirical curves, similar to the curve shown in Figure 3, for each tire type of interest. These curves make it possible to predict values of the cornering force (Fy) and the longitudinal force (Fx) given the current slip angle, camber angle, and normal force for any one of the wheelchair tires, including the caster wheels.

Figure 4 shows a simplified block diagram for a computer program that incorporates the wheelchair equations of motion along with the tire force curves just described. This model is very similar to those that have been used to study the stability of automobiles [3].

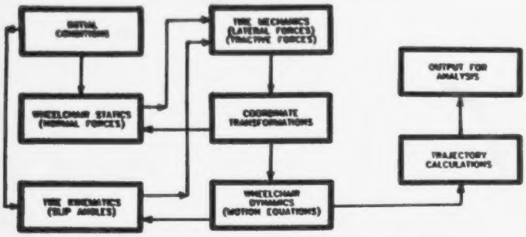
INITIAL CONDITIONS
TIRE MECHANICS (LATERAL FORCES) (TRACTIVE FORCES)
OUTPUT FOR ANALYSIS
WHEELCHAIR STATICS (NORMAL FORCES)
COORDINATE TRANSFORMATIONS
TRAJECTORY CALCULATIONS
TIRE KINEMATICS (SLIP ANGLES)
WHEELCHAIR DYNAMICS (MOTION EQUATIONS)

Figure 4 Simulation Block Diagram

An initial velocity in the forward direction is specified. At this stage, the wheelchair is assumed to be rolling unhindered, without the presence of any lateral or rolling resistance forces. At time t = zero, a small destabilizing disturbance is given. One way of accomplishing this is to specify an initial lateral velocity such as would be experienced when a wheelchair encounters a bump in the road. This disturbance will cause the wheelchair to drift away from the initial direction of motion.

Using the initial conditions, values for the slip angles at each tire can be calculated. By assuming fairly controlled motion and not allowing the wheelchair to pitch or roll, static relationships can be used to determine the normal forces at each of the wheels. Note, that any lateral cornering force will attempt to roll the wheelchair, resulting in unequal normal forces on each side of the chair.

Once the normal forces and slip angles have been found, the experimental curves are used to determine the lateral force and longitudinal force at each tire. The total force on the wheelchair is used along with the dynamic equations of motion to determine the initial trajectory and rotation. Each of these calculations is made for an extremely small interval of time. As the wheelchair moves and rotates, values for the slip angles and tire forces must be constantly updated. By performing this process over many time steps, it is possible to obtain an idea of how much a particular wheelchair will diverge from a desired course when subjected to a slight disturbance.

DISCUSSION:

The process of examining wheelchair stability by the methods which have been described is still in progress. It is hoped that valuable insight, leading to improved steering qualities for rear caster wheelchairs, will result from this work.

Rear caster wheelchairs have several inherent advantages. Electric wheelchairs often use rear casters because of the ease with which an obstacle such as a curb can be negotiated. Other considerations may make rear casters desirable for a manual wheelchair. For example, it is sometimes necessary to place restraining leg cushions at the front of a chair. These cushions can be large and bulky and hence may interfere with the normal pivoting of front casters.

Steering instabilities must be compensated for in order to maintain a desired path of motion. Electric chairs with this problem require much more manipulation of the joy stick. Unstable manual wheelchairs require additional physical exertion that may be impossible for some users to supply. If rear caster chairs are to become a suitable alternative to the naturally stable front castered chair, methods are needed to reduce the instability problem.

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TRENDS IN POWERED MOBILITY FOR SCHOOL AGED PHYSICALLY HANDICAPPED CHILDREN

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University of Tennessee, Memphis - The Health Science Center
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ABSTRACT

The trend of providing young, severely physically disabled children with the option of powered mobility is growing. We realize that through movement children learn, not only about their environment but also the true essence of what it feels like to be independent in mobility --- and they love it.

There are more technical solutions in the marketplace and better evaluation tools are being utilized. Several major obstacles including professional/parent attitudes and funding still remain. Documentation of research findings and clinical experience will help dispel fears and prove the tremendous advantages of independent movement for very young children.

INTRODUCTION/BACKGROUND

In recent years we have seen a growing trend to consider powered mobility for younger and younger children, especially those with severe physical disabilities. Traditionally powered mobility was not considered an option until a child reached their late teens. Even then if the child could ambulate at all, the decision for assistive mobility and powered mobility in particular was postponed.

Decisions of the clinicians to wait was based on several factors. Practically, until the last few years, there were few powered devices appropriate for use by small children. The existing chairs were huge! Traditional therapeutic practices suggested that if a child could ambulate at all or propel a manual wheelchair at all, they should be encouraged to do so. That philosophy is still valid but today we look at ambulation and manual propulsion in the context of the childs total lifestyle and also in terms of the quality of life. With this mind, we need to consider not only their ability to be mobile but the costs involved as well. Costs in this context include energy consumption, abnormal patterns of movement used to accomplish the task, especially when unsupervised, and the psychological costs of always being left behind by ones peers.

Studies of normal child development reveal the critical importance of independent movement. Piaget and Inhelder (1956) stated that infant's early sensory-motor experiences are the basis for learning. Held and Hein (1963) noted that cats who were passively manipulated through a maze did not learn the route, whereas those who moved by their own volition did. In similar research projects, it was found that humans who propelled their own wheelchairs learned a maze while those whose chairs were pushed did not. Wedell (1963) found that children who could not move independently through space were deficient in depth perception. Dennis (1973) studied children in orphanages who were deprived of normal opportunities to move and to receive sensory input and found a generally low level of intelligence. Zubek and colleagues (1963) also observed deficits in cognition and behaviors when mobility was restricted along with other sensory deprivations. Tatlow (1980) documented passive attitudes and vague body images in children who could not move independently.

In the past ten years a number of research projects monitoring the use of powered mobility systems by children have shown impressive results. Children as young as 24 months, an age when normal children have developed independent mobility skills, were found to be able to operate powered mobility devices safely (Butler, 1983).

Another study found that disabled children who used such devices became less dependent on controlling their environment through verbal commands, more interested in all mobility skills including ambulation, and much more active in peer activities (Paulsson, 1984).

A combination of the availability of technical options for young children, a moderation in the philosophy of some professionals, more established funding mechanisms for technology and the documented clinical and research experiences of successful early intervention, have begun to have an impact on the early provision of powered mobility for children with physical disabilities. A survey of the mobility modes of children enrolled at Shrine School in Memphis, Tennessee was performed and compared to a retrospective survey of the population of the same school in 1972-73 school year. Shrine School is an elementary and high school for children with physical disabilities. It is part of the Division of Special Education. There were 121 students enrolled in the school at the time the survey was completed.

Little information is available from 1972. There were a total of 172 children enrolled at the school. Of those children, nine used powered wheelchairs, eight of the children had a diagnosis of Duchenne Muscular Dystrophy and had access to adult sized unmodified powered wheelchairs made by Everest & Jennings (E & J) and owned by Memphis City Schools. The ninth child had a diagnosis of Quadramembral Amputee. He also drove an E & J adult sized chair but the chair was his own. All students were boys and all were over 10 years of age.

Today the picture of Shrine School students is quite different. There were 121 students enrolled at the time of this survey was done in early 1987. Twenty-two of the students are ambulatory and another twenty-one are ambulatory with assistance. Of the remaining seventy-eight, forty-seven are using manual wheelchairs, twenty-seven are using powered wheelchairs and three are using other forms of powered mobility (Figure 1). Only 4 of the powered devices belong to the school--and they are 4 of the original 8 which were purchased in 1972. The remainder of the powered devices are owned by the children and were purchased by the families, community groups, or medicare. It is interesting to note that of the ambulators, 6 have manual wheelchairs available for periodic use. Of those children using manual chairs, the occupational therapist offered the observation that four of them probably needed to be referred for consideration for a powered device.

DISCUSSION

Several trends are obvious from the results of the Shrine School survey. Of the total number of children at the school, 24.7 percent have powered mobility devices. By far the largest diagnosis of children in powered devices is cerebral palsy with 63 percent fit to date. The other noteable trend is for children to be given powered devices much earlier (Figure 2). Shrine School accepts children who are between the ages of 5 and 21. In the mobility survey, there are 7 out of 121 children between the ages of 5 and 10 who have powered devices whereas in 1972 there were none.

CONCLUSION

Shrine School in conjunction with the University of Tennessee Rehabilitation Engineering Program (UTREP) provide up to date access to technology for children with physical disabilities in the Memphis area. Trends in the provision of powered mobility for the students show that younger children and children with a variety of diagnoses are being offered powered devices. First hand knowledge of the students by the authors also indicates that children who are so severely physically disabled that they cannot use the standard joystick are considered just as able to drive, given newer technology and are therefore not discriminated against in regard to referral.

It is reassuring to see the growing trends for younger and more severely disabled children to have access to powered mobility. However, there are regions of the country where this is not happening. We must continue to document our success stories, develop more objective evaluation procedures, educate parents, professionals and third party payors as to the benefits for the children. We must urge on the basic researchers who are documenting the links between mobility and cognition so we have hard facts to back up the education process. The manufacturers must be urged to continue to develop mobility devices with alternate control options that look like a power machine every kid on the block wants. Not only will the children benefit, but it is felt that the next generation of persons with severe physical disabilities will be much more independent members of society.

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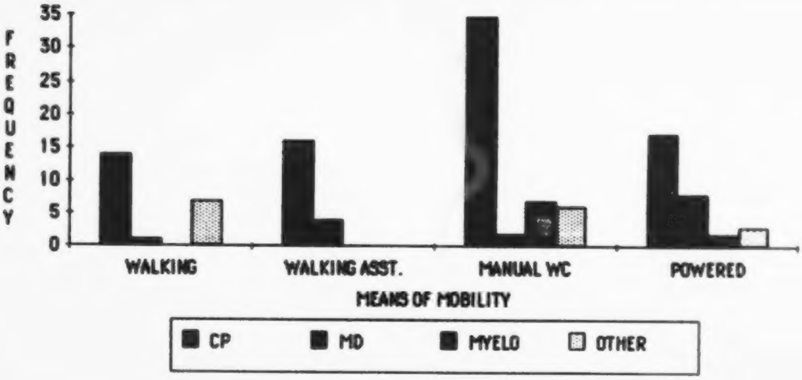
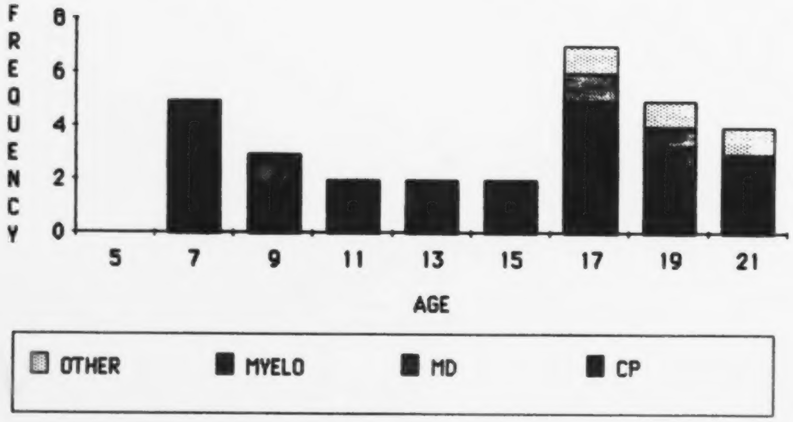


Figure 1. Mobility by Diagnosis

Figure 2. Powered Mobility Users



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EFFECT OF SEAT SURFACE STIFFNESS ON TRUNK MUSCLE ACTIVITY

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ABSTRACT

This study reports on a preliminary effort to define a relationship between the stiffness of a wheelchair seat and the activity in the trunk muscles of the lower back. A series of normal subjects were tested on a group of wheelchair seat surfaces that have different stiffnesses. The effect of the seat on the muscle activity was found to be accentuated when subjects propelled the manual wheelchair against a moderate resistance. By using this technique, the data could be collected in a shorter time than if the subjects were simply seated in the chair. By increasing the inflation pressure of the air filled cushions, and consequently the cushion stiffness, it was possible to decrease trunk muscle activity. The increased inflation pressure raised the interface pressures that were generated under the person, but by carefully adjusting inflation, it should be possible to provide improved postural stability without significantly compromising the pressure relief afforded by the wheelchair cushion.

INTRODUCTION

Seating spinal cord injured persons to reduce the risk of pressure sores has been a long standing field of rehabilitation research. The result has been the development(1) of new products that, when used properly, effectively redistribute forces from around the bony prominences. However, many of the most effective wheelchair cushions do not provide a stable surface from which to transfer or perform functional activities. Air-filled pressure relief devices have provided wheelchair users with a lightweight effective mode to redistribute their body weight away from the bony weight-bearing areas to those areas with thicker soft tissue covering. With a properly inflated, air filled wheelchair cushion, it is often possible to obtain peak pressures of less than 50mmHg and to provide a low pressure gradient over the load bearing area.

Air filled cushions have a long history of use in camping equipment and as wheelchair seats. New concepts incorporated into the design of wheelchair air filled cushions in recent years have made these devices more effective in redistributing weight as well as less subject to "bottoming out" under conditions of uneven loading. The modern air filled cushion also attempts to provide improved trunk stability for persons with high spinal cord injuries, while allowing air circulation at the seat/body interface to aid moisture and temperature control. The ROHO, Gaymar Soft Care, and Bye-Bye Decubiti systems represent products that incorporate innovative designs that make the air filled cushion a popular alternative to cushions fabricated from polymeric foams.

Rulings in California and Boston by local fire officials restricting the use of traditional foams for therapeutic bed surfaces and wheelchair cushions have resulted in an increased preference on the part of both users and health care providers for air filled cushions and mattresses. However, even the new generation of air filled cushions present several problems that limit their practicality and effectiveness.(2) Among these are individual occupations and lifestyles and the need to check the amount of air in the cushions on a daily basis.

Problems that affect the effectiveness of fluid-filled cushions relate to maintaining the correct amount of fluid in the cushion for optimal suspension; specifically the utility of air filled cushions is affected by how much air is needed to suspend the user and how sensitive the cushion's geometry is to the amount of air used to inflate it.

Inflation pressures between 30 and 35mmHg provide pressure relief performance that is close to optimal for most users.(2) However, when the cushion is inflated to such a pressure it may produce a support surface that reduces postural support and, over an extended period of time, this lack of torso support could contribute to problems such as scoliosis or other deformities that further limit functional control and mobility.

METHODOLOGY

To study the effect of wheelchair stiffness on trunk muscle activity, 5 normal subjects were evaluated on 4 different support surfaces. Two surface EMG electrodes were placed over the paraspinal muscles in the T6-L2 region. The output from the electrodes was telemetered to a strip chart recorder. The order of the seat surfaces was randomly assisnged and the surfaces included a standard wheelchair sling seat, a ½" plywood surface and an air filled cushion that was adjusted to minimize interface pressures and the same air filled cushion overinflated by 10mmHg. The arms of the wheelchair were removed and the subjects were instructed to lean forward slightly while propelling the wheelchair. This posture caused the back/hip angle to be 90°. For each data collection session the subject was seated on one of the wheelchair seats and propelled the wheelchair for 45 seconds after which time the surface EMG activity was recorded for 3 minutes. Between testing sessions the subjects were given 15 minute rest periods during which time they were allowed to lie down.

RESULTS

The results of the different stiffnesses of the seats are summarized in table 1.

The sling seat was used as the reference for the sample subjects tested and did in fact provide the lowest EMG activity. All subjects had highest muscle activity on the air-inflated cushion when it was adapted to produce minimum interface pressures. The cushion was easily deformed by the motion required to propel the wheelchair. By increasing the inflation and consequently the cushion stiffness, the effectiveness of the cushion in providing decreased trunk muscle activity could be improved. The increased inflation pressure in all cases raised the interface pressures; however, by carefully adjusting the inflation, it should be possible to reasonably satisfy both pressure relief and postural stability.

CONCLUSIONS

Based on the results of this preliminary study, the following conclusions have been developed:

1. The analyses of EMG data is useful in determining the amount of muscle activity required in relation to the stiffness of the support surfaces.
2. In all but one instance, lower back muscle activity increased with the least stiff support surface.
3. Since there is a varity of results in decreased lower muscle activity with seat stiffness, it could be useful to evaluate trunk muscles for patients prior to recommending a seat cushion.
4. Further research is indicated to determine whether there is a correlation between the stiffness of the support surface trunk muscle activity, and the development of spinal curvature and postural problems.

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Table 1

Seat Surface	Sling	Plywood	Overly Inflated Fluid Filled Cushion	Properly Inflated Fluid Filled Cushion
EMG Activity	100%	143%	175%	254%

BODY CONTOURS AND PRESSURE DISTRIBUTIONS OF NORMAL AND SCI SUBJECTS ON WHEELCHAIR CUSHIONS

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ABSTRACT

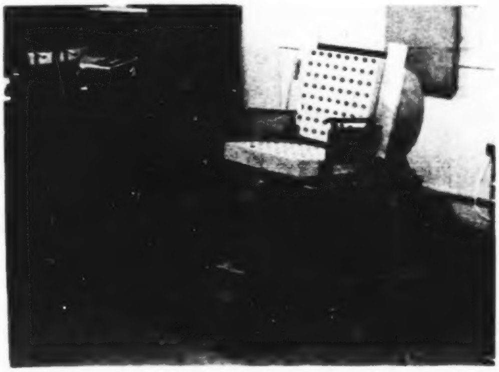
An Instrumented, Adjustable Fitting and Positioning Seat System (1) was used to study the Body Posture, Seat Cushions, Body Contours & Pressure Distributions corresponding to the Contours at the body-cushion interface, Anthropometric Dimensions and Body Center of Gravity in the Wheelchair Seating. Experiment was conducted on Normal, Paraplegic and Quadriplegic subjects, using typical seat and back angles and seat cushions. The purpose of this study was to characterize the Contour shapes and Pressure patterns for SCI and Normal subjects in wheelchair seating. The information should be useful in designing production and custom cushions for effective seating and support systems.

INTRODUCTION

Transmission of forces across soft tissues is inevitable when a wheelchair is used to provide functional support to persons in the gravity environment. The Intrinsic factors(specific disability, human factor, etc) and Extrinsic factors(cushions, supports and wheelchair components) as well as Ergonomics factors(body posture and interfacing of body and support) are three major determinants for load distribution over the tissue-support interface. To provide a basis for more comprehension study of the biomechanics on interfacing between seated patients and body supports, a clinical seating system(Figure 1) was developed to quantitate load bearing characteristics of the tissue-cushion interface and to evaluate the functional effects of these three factors on load transfer in wheelchair seating. The seat is also useful to the determination of acceptable seating posture and to aid in the Anthropometric data collection for the seat patients in seating evaluation.

Seat contours and pressure distributions as well as body center of gravity in the horizontal plane were measured & analyzed for Normal, Paraplegic and Quadriplegic subjects in polyurethane, viscoelastic, lamina and ROHO cushions. The contours and pressures were also recorded in response to change of body posture. The information of human body response to cushion supports and body positioning are useful in providing engineering design data and fitting procedures for effective seating and support system to promote the tissue survival in wheelchair seating.

Fig. 1: Instrumented, Adjustable Fitting and Positioning Seat System



METHOD

Change in the load transfer at body-cushion interface were evaluated to determine the effects of typical seat cushions and seat positioning and spinal cord injury on body contours and interface pressures as well as body center of gravity in the horizontal plane. Twenty-four subjects were included: 8 with paraplegic, 8 with quadriplegic and 8 able-bodied persons. The four cushions were used. With the subject seated, initially the fitting seat was adjusted to an acceptable position judged appropriate by clinical experience and subject response. The contour and pressure and body center of gravity were measured for this sitting position. For each cushion, then the seat was adjusted to 5^0 and 10^0 angle to the horizontal, and for each seat angle the back was adjusted to a 95^0 and 100^0 angle. A three-factor experiment with repeated measures for analysis of variance was performed to examine the effect of seat angle, back angle, cushion type, and interaction of these factors on contour and pressure.

To perform quantitative analysis, the seat contour was characterized by four parameters, including maximum cushion indentation, radii of contour at the location of the maximum indentation, soft tissue thickness from the apex of bone near the I.T. to skin surface and total sitting surface area. The interface pressure was characterized by two parameters, including maximum pressure and maximum pressure gradient at the location of maximum pressure. These parameters were test for significance following the three factors of treatment. Qualitative analysis was also perform to describe contour shapes and pressure patterns for subject groups in different types of cushions.

RESULTS

Body-cushion interface showed that at the sitting area the contour shape and pressure profile corresponding to the contour were qualitatively similar to each other (Fig. 2,3,4 & 5). The interface pressure was increased in proportion to the depth of cushion deflection along the interface(Fig. 6&7). Body contours and pressure distributions were affected by the individual and the cushion type as well as body position. The body-cushion interface, as subjects were sitting in their comfortable positions on cushions, showed the peak pressure and highest indentation occurring under the I.T. and gradually decreasing down to periphery of the support area. In some individuals the peaks were found under the sacrum and posterior greater trochanters.

Qualitatively, the contour shapes and pressure patterns for three body types in their comfortable positions on the four cushions (3"-thick polyurethane and viscoelastic and lamina foams, and 4"-thick ROHO) shoewd (Fig. 8 and 9) :

(1) Able-bodied persons presented a double contour with symmetric shape, representing the two buttocks , on all four cushions.

(2) Persons with Flaccid Paraplegia (below or at the T-12 injury level) presented only a single contour with peak near the midline of buttocks on all four cushions.

(3) Persons with Paraplegia(above the T-12) and the Quadriplegics might present a double contour with asymmetric shape on the foam cushions and peak of the double contour was much deeper than that of the Normal. Only a single contour was presented for these persons on the ROHO. Single contours resulting from these persons were much shallower than those of the Flaccid Paraplegic, but the location of the peak deviated from the midline of buttocks or was located near the sacrum.

(4) The Paraplegic and Quadriplegic subjects had less uniform pressure distribution and body contour, and higher peak pressure and cushion indentation compared to that of normal persons. The Flaccid Paraplegic was found to have a relatively high cushion indentation & pressure over bony prominences, followed in descending order by the Paraplegic with injury levels above T-12 and the Quadriplegic, the Normal Males with an average weight, and the Normal Females with an average weight.

(5) The interface at distal thigh and mid-thigh had a relatively small cushion indentation and pressures compared to the buttocks. Pressure less than 35 mmHg was found under these areas for all three body types in all four cushions.

(6) For each person, the equilibrium support surfaces showed that the ROHO cushion has relatively high vertical deflections over bony prominences and large support area in the sitting surface, followed by the viscoelastic foam, the polyurethane foam and lamina foam.

(7) For able-bodied persons, the body center of gravity was typically on the center line of the seat. For those with SCI, the body center of gravity was always away from the center line , no matter how carefully the person is positioned in the Seat.

Fig. 2 Seat Contours for Flaccid Paraplegic on Lamina and ROHO cushions : The dotted curves represent contours for a L-1 Para. male and solid curves for a T-12 Paraplegic male.

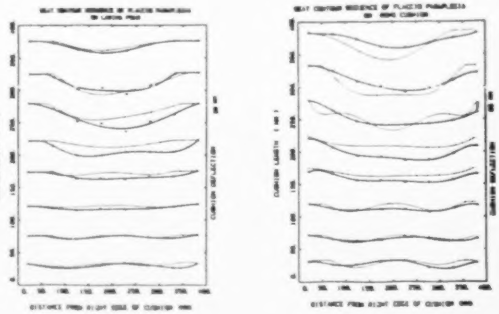
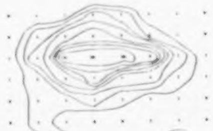


Fig. 3 Pressure distributions corresponding to the seat contours for the L-1 Paraplegic male as shown on Fig. 2(the dotted curve)

Pressure on Lamina foam



Pressure on ROHO

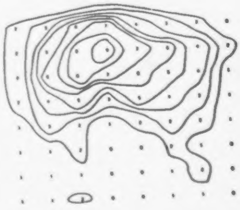


Fig. 4 Seat Contours for SCI persons on Lamina and ROHO : the dotted curves represent a C5-C6 Quad. female and solid curves for a T-9 Para. male.

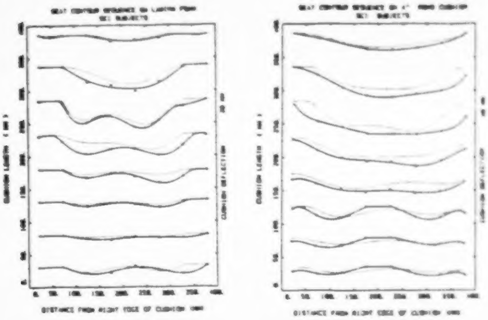


Fig. 5 Pressure Distributions corresponding to the seat contours for the C5-C6 Quad. female as shown in Fig.4 (dotted curves)

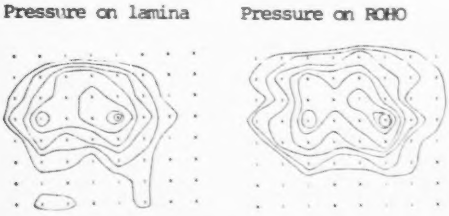

Pressure on lamina Pressure on ROHO

Figure 6:

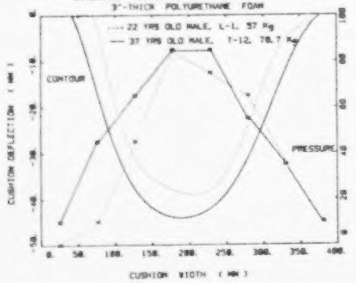


Figure 7:

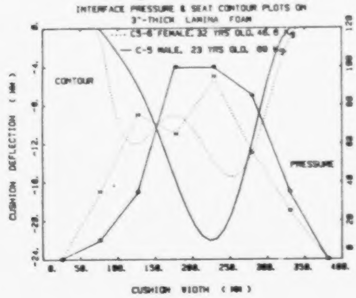


Figure 8:

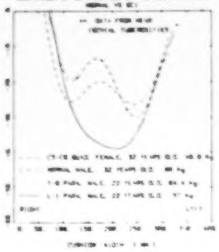
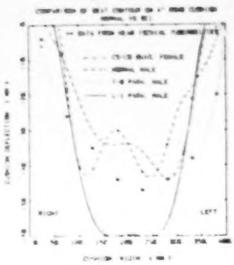


Figure 9:



Quantitatively the effect of cushion types on contour and interface pressure was found to be significant (p 0.05) for each of the three subject groups (2). The statistical results also indicated significant differences between Normal and Spinal Cord Injured Seat Contour and Interface Pressure, as well as between Flaccid Paraplegic and Spinal Cord Injured with injury level above T-12.

However, the results showed that most of the effect of seat angles and back angles on contour and pressure was not significant (p 0.05). These results agreed with those of the previous study, in which no general trend was found for characterizing the effect of body positioning on change of seat contour and interface pressure. Thus, to provide a suitable body posture and support system in seating, the individual fitting , positioning and seating evaluation seemed most appropriate.

CONCLUSIONS

The adjustable seat was found to be easy to use and accurate for the measurement of disability specific anthropometric data, body contour and pressure distribution and location of body center of gravity The result will be useful to characterize clinicaly determined seating configuration and load transfer at the tissue-cushion interface. The information should be useful in designing production and custom cushions to promote tissue survival in wheelchair seating.

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EFFECT OF SEATING POSTURE ON PRESSURE DISTRIBUTION

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ABSTRACT

Pressure distribution, as an index of seating support, was studied in relation to variations in posture, in six different commercially-available office chairs. Pressure tests were conducted on eight subjects (4 males, 4 female), in each of three angles of forward flexion (70°, 90°, and 120°), on all six chairs. Pressure distribution was measured on seat pans and backrests using a pressure monitor; readings were linearly interpolated and isobaric contour lines were drawn for each experimental condition. Qualitative analyses were provided by comparing differences between flexion angles and between chairs. Seat pan pressure distribution was found to be similar for all chairs but varied with flexion angle. Backrests offered little spinal support in the forward-flexed posture and insufficient support to the reclined user. The greater thc angle of recline, the less support was provided to the lordosis region. Results are discussed in light of spine biomechanics and implications for seating design.

INTRODUCTION

Seated postures have been recognized as contributing to an increase of low back pain in the workplace (2). To aid in the development of an "ideal chair," researchers have identified a number of design considerations (1,4,5,6) which include anthropometric factors, muscle activity (EMG), comfort, and pressure distribution.

Although pressure distribution has been investigated in various types of seating, commercially available office chairs have not yet been studied in this regard. Pressure studies have been conducted using specially made experimental chairs as well as wheelchairs and wheelchair cushions (3). Jurgens (5) has noted that, although pressure distribution is not the sole determinant of seating quality, it should be an integral part of any investigation of human seated support.

By examining the pressure distribution interface between the person and chair, information can be obtained about how and where a particular seat supports the body. Using a pressure mat on automobile seats, Kamijo et al. (6) compared objective assessments of pressure with self-reported comfort and reported that static pressure distribution patterns correlated with the perceived comfort of auto seats.

The support provided by a chair has been identified as an important factor in determining posture, but pressure distribution may vary with the specific posture assumed. For example, Hertzberg (4) observed a backward shift in force contours when backrest inclination changed from 90° to 115°. Also, he found that differences in buttock pressure between 90° and 105° of backrest tilt show reductions in overall weight and redistribution of the weight backwards.

The present study describes the pressure distribution of a number of commercially available office chairs. Pressure measurements were obtained with an air cell transducer on both the seat pan and backrest; pressure contour maps were then generated for each of the chairs.

MATERIALS AND METHODS

Six commercially available office chairs were obtained for this study. The six chairs were all different and comprised three types:

Posture Tilt Chair. Commonly called a stenographer's chair, this model incorporates a moving backrest with a stationary seat pan.

Swivel Tilt Chair. Back and seat pan are fixed and thus move as a unit, as in a common rocking chair.

Synchronious Tilt Chair. Back and seat pan move simultaneously and in a fixed ratio. For example, for every 3° of back inclination, the seat pan may tilt backward 1°.

The six individuals chairs were as follows:

Chair #1: Posture tilt. Half backrest (width = 38cm, height = 30cm). Backrest adjustable in height
Seat pan (width =48cm, depth = 48cm)

Chair #2: Same as Chair #1. Armrests (height = 21cm)

Chair #3: Same as Chair #2 but with a full backrest (width = 38cm, height = 38cm)

Chair #4: Swivel tilt. Full backrest (width = 51cm, height = 46cm). Seat pan (width = 53cm, depth = 48cm). Seat pan/backrest unit pivoted about hinge 24cm behind front of seat pan. Armrest (height = 18cm)

Chair #5: Posture tilt. Half backrest (width =35cm, height = 33cm). Seat pan (width = 38cm, depth = 43cm). Seat pan tilt adjustable from 5° to 8° backward tilt. No armrests.

Chair #6: Synchronous chair. Full backrest (width = 38cm, height = 51cm). Seat pan (width = 44cm, depth = 50cm). Seat pan tilt adjustable from 5° to 8° backward tilt. Seat pan hinged at front of seat.

The following adjustments were made to the chairs, as necessary.

(1) Seat pan height was adjusted for all chairs such that the tibia was at 90° to the femur. The femur was horizontal to the floor when individuals were seated erect, with feet flat on the floor.

(2) Backrests of Chairs #1, #2, #3 and #5 were adjusted in height such that the convex curve of the backrest was positioned at the lordosis of the subject when seated erect.

(3) Backrest angles were locked in place during each test for all chairs except #4, due to variability in the spring force of backrest.

Eight subjects (4 males, 4 females) participated in the study. Heights ranged from 157 to 193 cm (mean=173) and weights reanged from 52 to 99 kg (mean=69). Each subject was positioned at 70°, 90°, and 120° forward flexion. The angle was measured from a horizontal plane to the floor.

Chairs #5 and #6 were also tested with seat pans adjusted in the two most extreme positions.

Pressure distribution was measured on both the seat pan and the backrest using two Oxford Pressure Monitors manufactured by Talley Medical Equipment Ltd, Oxford, England. The device uses 25 pneumatic load cells arranged in a 5 x 5 matrix on a 30cm x 30cm mat. Pressures were first recorded at the seat pan; the mat was then removed and secured to the backrest where pressures were again recorded. Air cell transducers have been shown to be a viable method of describing the pressure distribution at the user/chair interface. However, interpretation of the absolute values obtained for pressure can present problems (8,9). Thus, pressure distribution was assessed using two qualitative methods. Readings from the pressure mat were entered into an AT&T PC computer where values of pressure were linearly interpolated. In the first method, sixteen hundred points within the 30cm x 30cm area of the mat were calculated for both the seat pan and backrest, and isobaric contour lines were drawn, providing a two-dimensional or topographic view for each experimental condition. In the second method, pressure patterns were plotted so as to allow a three-dimensional representation.

Data were evaluated by studying pressure patterns of all chairs at each flexion angle. First, data mappings were arranged so that comparisons (of location and of the relative "high" and "low" pressure points) could be made between the various flexion angles as well as between chairs for each individual subject. Four observers individually studied the mappings, documenting similarities and differences among chairs and among postures.

A second method for evaluating the data was done by normalizing the pressure reading for a 150 lb. person. The eight subjects' pressure values were averaged and plotted three-dimensionally. The data were then compared for the difference between 70° and 90° forward flexion and between 90° and 120° forward flexion. Variances between chairs (at 90° forward flexion) were also compared. Pressure maps were compared by subtracting readings of one pressure distribution from the corresponding readings of a second pressure distribution. A resulting pressure map was then generated from the difference values. Evaluating the generated pressure map indicates regions of higher or lower pressure between the two test situations.

RESULTS

Several pressure distribution patterns were exhibited by all six chairs and are consistent with previous findings (4,5,6,8). The points of highest pressure were found under the ischial tuberosities and under the thighs. Seat pan pressures at the ischial tuberosities generally increased in all chairs as posture changed from 70° to 90° forward flexion, but decreased as subject reclined to 120° forward flexion. Pressure under the thigh was highest at 70° forward flexion and gradually decreased as the subject reclined to 120° forward flexion. It was also noted that, as subjects reclined to 120° forward flexion, pressure increased at the coccyx, presumably because of backward rolling of the pelvis in this reclined position.

In the 70° position, pressure at the upper and lower back was at a minimum for all chairs. As subjects moved from 90° to 120°, pressure on the back moved up and became more localized in the scapular region (upper back) and pressure decreased at the lower back.

The posture tilt chairs as a group (Chairs #1, #2, #3 and #5) showed higher seat pan pressures than the other types of chairs. Chairs #1, #2 and #3, with the same seat pan design, showed that different backrests did not vary the seat pan distributions. The armrests of Chairs #2 and #3 had no apparent effect on the distribution. The full back of Chair #3 caused higher pressure at the bottom of the backrest due to interference with the buttocks. This also tended to hinder upper back support at 90° and 120° flexion. The half backrest of Chairs #1 and #2 allowed space for the buttocks at the back of the seat pan. Although Chair #6 had a full backrest, it did not have the same effect as Chair #3 of buttock pressure on the backrest. This appeared to be due to the fact that the bottom of the backrest was concave enough so as not to contact the buttocks.

Seat and back pressures for Chair #4 were more uniformly distributed then the other chairs. No back support was noted for Chair #4 at the 70° position. However, there was a tendency for pressure to increase under the thighs for Chair #4 as the subject moved from 90° to 120°.

Chairs #5 and #6 showed an increase in pressure under the thighs, but a decrease in pressure under the ischial tuberosities, as the seat pan was tilted back from 5° to 8°.

Two observers noted a tendency for asymmetrical loading on the left side for all the chairs.

DISCUSSION

All chairs tested showed the same general seat pan pressure distribution as has previously been described in the literature. The finding that the seat pan pressure is reduced and moves rearward with increasingly inclined postures confirms Hertzberg's (4) single observation in a special seat. Although the relative values of pressure may have been affected, the addition of armrests did not seem to change the distribution of pressure on the seat pan.

Two often-cited characteristics of good seating are adequate back support and the ability to allow for movement or altered posture (2). Keegan (7) suggested that risk of low back pain is increased by seated postures which necessitate a decrease in the trunk-thigh angle with consequent flattening of the lumbar curve. Such postures may promote stretching of the posterior longitudinal ligaments and may thus contribute to posterior protrusion of a degenerated lumbar disc. Ligament stretch is minimized in sitting postures when the backrest helps position the spine in a relatively "normal" lordosis. Andersson et al. (1) have reported that proper lumbar supports absorb part of the weight of a reclined individual, thus reducing the load on the lumbar spine. Lumbar supports also help prevent flattening of the spine and corresponding disc pressure.

Disc pressure is also reduced with increased backrest inclination. In a reclined position, muscle activity is reduced and loads are transferred to ligamentous structures. Thus, from a biomechanical perspective, one would recommend that chairs be designed to position the spine in lordosis and to support it through the range of motion of the chair.

The chairs tested here have not been found to provide adequate support to the back in the forward flexed position, which is typical in the workplace (e.g., when working at a desk or bench). These six chairs appear to support the lordotic curve of the spine best when an individual maintains an upright, erect posture. However, when reclined, the pressure distribution patterns show that support is displaced upward, toward the scapular region instead of remaining at the lordosis. The swivel tilt chair provided the best lordotic support, perhaps because of the fixed relationship of the back to the seat pan. However, an increase of pressure under the thighs was observed as the feet left the floor. The backrest pivots of the other chairs do not coincide with the anatomical pivot of the trunk, and thus may cause a shear motion between the backrest and the back of the seated individual. This phenomenon was demonstrated by Warren et al. (10) in the case of reclining wheelchairs. They subsequently designed a four-bar linkage to replace the traditional single pivot, in order to reduce the amount of shearing motion.

The observation of asymmetry is of interest, since Jurgens (5) also noted a strong loading on the left side.

CONCLUSIONS

1. Pressure distribution on the seat pans of six commercially available office chairs has been found similar to that described for other types of chairs and experimental seats.
2. Seat pan pressure at the ischial tuberosities increased as the posture changed from 70° to 90° forward flexion.
3. Seat pan pressure at the ischial tuberosities decreased as subject reclined to 120° forward flexion. It was also noted that, as the subject reclined to 120° forward flexion, pressure increased at the coccyx.
4. In the forward-flexed position, which is a typical working posture at desks and workbenches, the backrest of these chairs offered little or no support. Also, pressure under the thighs was highest in this position.
5. As the backrest was reclined to 120°, support moved from the lordosis region of the spine to the scapular region. Thus, less support was provided for maintaining the lordosis in reclined positions.
6. The swivel tilt type of chair appeared to be the best in supporting the lordosis in the reclined position with a concomitant increase in thigh pressure. REFERENCES

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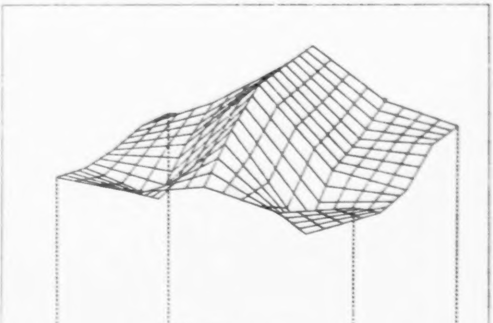

EFFECTS OF BODY POSITION AND CENTER OF GRAVITY ON TOLERANCE OF SEATED POSTURES

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ABSTRACT

Previous work has shown that postures deviating from an upright seated position, thereby shifting one's center of gravity (or mass) are not tolerated as well as an upright position. The present study was designed to distinguish between effects of body position and center of gravity (CG) shifts on tolerance of seated postures. Ten subjects were tested in each of four static conditions: (1) 0° FF (upright) with 0° CG displacement; (2) 0° FF with 30° CG forward displacement; (3) 30° FF with 30° CG; (4) 30° FF with a 0° CG displacement. Muscle fatigue and subjects' reported pain were also monitored. The upright posture (0° FF) with 0° CG displacement was tolerated longer than any of the other three conditions; however, the findings also indicate that body position and CG displacement may equally affect sitting tolerance time. Low back pain was the most prevalent form of discomfort; muscle fatigue was evident and may be the limiting factor in sitting tolerance.

INTRODUCTION

The relationship between manual lifting tasks and low back pain (LBP) is well documented. The NIOSH Work Practices Guide for Manual Lifting presents data, derived from a combination of epidemiological, biomechical, and psychophysical research findings, which establish limits for two-handed lifting tasks for various postures (2). It has been observed (4) however that workers may suffer from low back pain even when their jobs require little or no lifting. Such workers include drivers, computer operators, typists, and others who are required to assume static postures for long periods of time. No limits have yet been reported in the literature for static posture tolerances and little information exists for dynamic postures. This is in contrast to the extensive work done regarding load-lifting limits (2).

In a previous sitting study (6), tolerances were determined for various postures of forward flexion, lateral bending, and rotation. The outcome measures were tolerance time, muscle fatigue, and shift in the body's center of gravity. Results showed that the length of time for which a posture can be sustained decreases as the center of gravity of the body is displaced further from the neutral, upright posture.

One question arising from this previous work is what causes onset of pain or muscle fatigue for a given posture. Two variables or factors which could account for onset of pain are change of posture, which might reduce muscular efficiency, or change in center of gravity, which might require muscles to work harder. The purpose of the present study is to determine the extent to which these two factors affect seating discomfort.

MATERIALS AND METHODS

Ten subjects (5 male, 5 female) with no previous history of low back pain participated in the study. Subjects' ages ranged from 19 to 34, with a mean of 24. Height ranged from 152 cm to 193 cm (mean=173 cm) and weight ranged from 52 kg to 81 kg (mean=69 kg). Each subject was tested twice by random assignment, in each of the four positions listed below, for a total of eight tests.

(a) 0° forward flexion (FF) or erect, with the same center of gravity (CG) as sitting in 0° FF (0° FF - 0° CG)
(b) 30° FF with 30° CG thus, a naturally-occurring shift in CG (30° FF - 30° CG)
(c) 0° FF with weights attached to a chest harness used to simulate 30° CG forward displacement (0° FF - 30° CG)
(d) 30° FF with weights attached to the back of a chest harness used to simulate CG at 0° FF displacement (30° FF - 0° CG)

Subjects sat on a modified comfortable chair that had its backrest removed. The chair was adjustable for pan height so that the lower leg was at a 90° angle with the thigh. The position of the center of gravity was recorded for 0° and 30° forward flexion before each test.

A wind-surfer's chest harness was worn by the subject for each test. For the two test positions which involved an artificial shift of center of gravity, a horizontal rope was hooked to the front or back of the harness. The other end of the rope was attached to weights through a pulley in order to shift the subject's center of gravity. Center of gravity was monitored through out the test by a force plate to which the chair was bolted.

Electromyographic (EMG) electrodes were placed 3 cm from each side of the midline at the L3-L4 level of the erector spinae muscles. EMG activity was recorded at the beginning and end of each test. Muscle fatigue was evaluated via a spectrum analyzer which detects shifts in the center frequency of the EMG power spectrum density function (PSDF). Correlations have shown a decreased shift in center frequency as the muscle fatigues (7).

Position was assessed by measuring the degree to which the trunk deviates from its position in the erect sitting posture and was monitored by tactile feedback clamps that did not restrain the subject. These clamps, which simply encompass the shoulder, were first set to a predetermined position which allowed positioning of the subject within 30 seconds. A calibration jig, which mimics the anatomical dimensions of the subject, made it possible to preset the clamps without using the subject as a model.

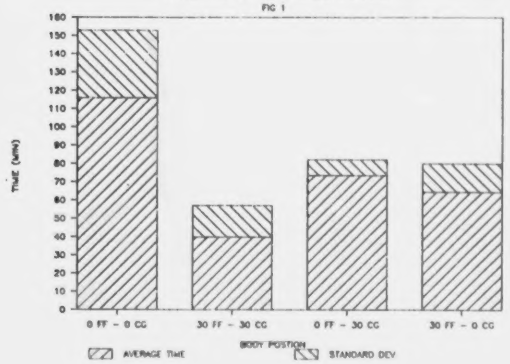
A visual analog scale (VAS), a form of cross-modality matching, was used to assess level of discomfort or pain. The VAS has been reported to provide valid and reliable ratio scale measurement of both clinical and experimental pain (3,5). The scale requires a respondent to place a vertical mark on a 10 cm horizontal line, the endpoints of which were labelled "No Pain" and "Excruciating Pain." The VAS scale was given to the subject every 10 minutes for the duration of the test.

RESULTS

Figure 1 shows the means and standard deviations of tolerance time for each of the four postures. The average time a subject could sit at 0° FF - 0° CG, was 115 (SD=37) minutes. This posture was tolerated longer than the other three postures ($p < .01$). The position of 0° FF with weights added to simulate a center of gravity at 30° FF (0° FF - 30° CG), was tolerated for an average of 73.5 minutes (SD=9.3). The position of 30° FF with weights added to simulate center of gravity at 0° FF (30° FF - 0° CG), was tolerated an average of 64.6 minutes (SD=15.5). No difference in tolerance time was found between 0° FF - 30° CG and 30° FF - 0° CG, although both of these postures differed from 0° FF - 0° CG and 30° FF - 30° CG. 30° FF - 30° CG was the least tolerated when compared with the other three positions, with a average time of 39.8 (SD= 17.2).

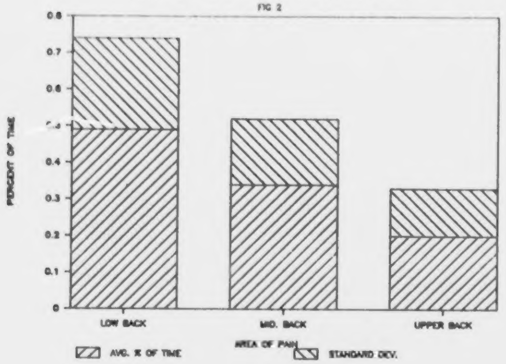
TIME TO PAIN TOLERANCE

FIG 1



TOTAL % OF PAIN DURING TEST

FIG 2



Results of the discomfort ratings showed an increase in discomfort in all test subjects as a function of time. Figure 2 shows the area or location of pain for all tests and subjects. Low back pain was the prevalent complaint. Subjects experienced low back pain 49% of the time (SD=25%) throughout the duration of the test. The second most prevalent pain was in the middle back and occurred 34% of the time (SD=18%). The least prevalent pain was upper back pain, experienced 20% of the time (SD=13%).

Both tolerance time for these postures and percent of time that pain was experienced varied considerably among subjects, as demonstrated by the high standard deviations.

Interpretation of the electromyographic recording of the muscle activity demonstrated that, for all test conditions, the erector spinae muscles fatigued.

DISCUSSION

The results of this study indicate that a seated posture with 0° FF - 0° CG is the most tolerable sitting position. Positions which involved either a shift in center of gravity (while maintaining 0° FF) or a shift in the flexion angle (while maintaining the same center of gravity) were significantly less tolerable. The least tolerable posture was that of 30° FF with a naturally occuring forward shift of center of gravity.

These findings suggest that a forward shift in center of gravity, which requires support via the back muscles, results in a reduction of tolerance time. Changing one's posture while maintaining a constant CG also results in decreased tolerance time. The greatest effect on tolerance time resulted from the combination of forward shift of CG and forward flexion. Thus, altering center of gravity and/or posture may adversely affect sitting posture tolerance time. However, there was no apparent difference between the ideal posture (O°FF) with the inferior CG (30° CG) and the ideal CG (0° CG) with the inferior posture (30°FF). This would lead one to conclude that both posture and CG shift have substantial and equal effects on the outcome of sitting tolerances (fig 3).

fig. 3

	0 FF 0 CG	30 FF 30 CG	0 FF 30 CG	30 FF 0 CG
0 FF-0 CG				
30 FF-30 CG	.01			
0 FF-30 CG	.01	.1		
30 FF-0 CG	.01	.1	N.S.	

Since fatigue in the erector spinae muscle group was observed and since subjects reported pain in the low and middle back for much of the testing time, it appears likely that posture tolerance time may be a function of the muscles. Chaffin (1) and others have shown that the further from the body a weight is lifted, the more force is generated at the disks and the more tension occurs in the lumbar muscles. A similar phenomenon is suggested by the present findings, in that the more poorly tolerated postures were those in which the center of gravity was shifted the furthest from the upright position.

CONCLUSIONS

(1) Sitting upright (0° forward flexion) was observed to be more tolerable than postures which combined varying degree of forward flexion and forward shifts of center of gravity.
(2) A sitting posture at 30° forward flexion with a forward shift of center of gravity was the least tolerated posture.
(3) Changing either or both the center of gravity and posture may have an adverse effect on sitting posture tolerance time.
(4) Posture and CG shift have equal effects on the sitting tolerance.
(5) Complaints of low back pain were more prevalent than either middle or upper back pain.

ACKNOWLEDGEMENTS

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A DYNAMIC MODEL OF TISSUE DEFLECTION IN A SEATED INDIVIDUAL

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ABSTRACT

A dynamic mechanical model of the soft tissue at the seating interface is presented. The basic premise for developing this model is that pressure sores are better related to tissue distortion rather than the seating interface pressure. In addition, the tissue is viscoelastic and so the distortion (or deflection) exhibits creep. The proposed model is a simple, one-dimensional, third order system. The system dynamics are examined under various load conditions. It is concluded that this initial oversimplified model is unable to accurately represent the tissue distortion. However, it does present conceptually the dynamics of soft tissue under load to provide a good beginning for further model refinements and improved understanding of pressure sore etiology.

INTRODUCTION

Pressure sores are a major problem among the spinal cord injured (SCI) population, particularly those with loss of sensation. Besides the quality of life issues (loss of independence, mobility, etc.), the financial burden to the individual and society is extensive. In 1977, annual costs in the USA were estimated at $750,000 (3). With increased health care costs, this estimate now approaches $2 billion.

The development of a pressure sore is a complicated event which involves mechanical as well as biochemical forces. However, most investigators believe that the primary event leading to a pressure sore is blood flow occlusion. Some investigators have also expanded this concept to include the occlusion of lymph vessels and disturbance of the interstitial fluid flow (10).

Usually, the tissue blood flow has been related to the external pressure on the skin (1,2,8). However, the many studies which have attempted to relate blood flow occlusion to only the interface pressure have provided an incomplete picture of the event. For example, Houle (6) set a maximum seating interface pressure of 32 mm Hg (based on average capillary blood pressure). Subsequent experiments on a variety of seating cushions used by the SCI population revealed that none of the cushions fit this criteria. Yet, a good percentage of the SCI population sitting on these same cushions do not get pressure sores.

Tissue distortion provides an accurate display of the internal stresses in the tissue. Chow (4) developed a wood and gel model to demonstrate the effect different external loads have on the tissue shape and stress distribution. The model was made of a wooden core to simulate bone and surrounded by PVC gel with viscoelastic properties comparable to that of human soft tissue. Maximum tissue stress was computed based on the tissue (or gel) deformation rather than on the applied pressure or load. For this paper, it is proposed that tissue blood flow, and thus tissue breakdown, is better related to the distortion of the tissue rather than the externally applied pressure. Furthermore, the tissue distortion (x) is assumed to be a funtion of time (t), the externally applied forces (F), and the tissue's inherent mechanical properties (K), or

$$x=f(t,F,K) \qquad (1)$$

DEVELOPMENT OF THE MODEL

The development of a pressure sore is certainly a dynamic effect (i.e., a function of time). One way of looking at this dynamic behavior was demonstrated by Reswick and Rogers (11). The authors developed a plot of acceptable/unacceptable pressures vs. time of sitting for SCI individuals. The plot illustrated that as sitting time increases, the allowable interface pressure decreases. In another paper, Kosiak et al. (8) demonstrated that the tissue can tolerate higher pressures for longer duration if the loading is cyclic. Consequently, standard practice for most SCI individuals is to perform periodic wheelchair pushups of 15-60 seconds in duration every 15-30 minutes.

The time dependency is a result of two entirely different phenomenon. First, physiologically, live tissue will continue to function for a time even after all blood and nutrient supply is removed. Second, the soft tissue exhibits viscoelastic behavior. This paper focuses on the second phenomenon.

Mechanical Analogy. A schematic of the tissue at the seating interface is shown in Figure 1a. From the figure it is seen that the system is made of soft tissue, a seat cushion, blood supply into the soft tissue, lymph vessels, and bone. The proposed mechanical representation of the system is in Figure 1b. It is a 3rd order system. The combination of elastic elements K1 and K2, with resistive element B2, represent the viscoelastic

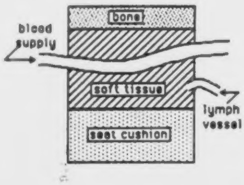

Fig. 1a
Schematic of System

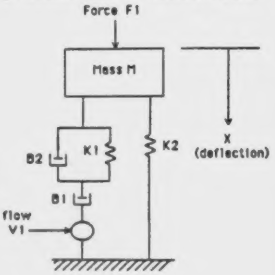

Fig. 1b
Mechanical Representation

properties of the soft tissue. Resistive element B1 results from the tissue fluid being forced into or out of the tissue by the external forces (9,10). Flow V1 is a flow source of fluid into the tissue from the blood supply. This initial formulization does not include seat cushion parameters.

The values assumed for the mechanical elements of the model are based on published reports. The rational for each element follows.

a) Elastic elements K1 and K2 are developed from the indentor studies of Sacks et al. (13). The elastic behavior is nonlinear with the stress/strain curve exhibiting a toe region followed by a linear region. This type of stress/strain behavior is typical of most soft connective tissue. The two regions of the curve are approximated using straight lines.
b) Resistive element B1 represents the flow of interstitial fluid out of the tissue. A theoretical relationship has been developed for this fluid flow (Q) based on pressure gradient, the volume fraction of the fluid, and the hydraulic conductivity of the medium (10). The resistive element B1 is assumed constant.
c) The flow source V1 represents the flow of fluid into the tissue from the capillary bed. The value for this is obtained from a theoretical relationship which relates the fluid exchange to tissue permeability, capillary diameter, capillary length, and blood viscosity (7). The flow source V1 is assumed constant.

Note: For the purpose of this simulation, a cylinder of soft tissue 35 mm in diameter by 40 mm length (relaxed) is considered. All parameters and system inputs are calculated based on this assumption.

METHODS

The bond graph technique was used to aid in analysis of the proposed model (12). Bond graphs provide a systematic approach for developing a set of equations relating the various parameters of a system. A bond graph developed from the mechanical model proposed in figure 1b is shown in figure 2. The computer programs Enport5 and Enport6 (5) were utilized for numerical solutions.

The system response to force input (F1) was examined using this method. The output of interest is a simulation of skin deflection (x) as a function of time (t). Two different types of force inputs were utilized. The first was a simple step input to determine the steady state value. The second was a simulation of a wheelchair pushup for doing pressure relief. This was accomplished by applying a static load for 15 minutes followed by no load for 30 or 60 seconds.

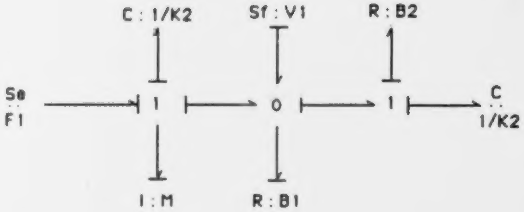

Fig. 2. Bond Graph of system. Element labels correspond to those of fig. 1b.

RESULTS

An attempt was made to use quantitative values in the mechanical model which approximate those in soft tissue. Validation of the viscous elements B1 and B2 and of the flow source V1 is not feasible because no known published data for these exist. The elastic behavior is also difficult to validate because most published data does not account for the time variability. A static stress-strain curve for the model can be generated by recording tissue deflection at a given instant in time following application of the load. This was done for the model at time = 30 seconds. This exercise demonstrated that at this instant in time the total elastic behavior of the model is more compliant (less stiff) than published results (13).

A typical output of skin deflection for a step input of 0.5 N force is shown in fig. 3. The system response is exponential with a time constant estimated at 6 minutes (system will reach full skin deflection at 30 minutes).

The response to the simulated pressure relief is shown in figure 4. Pressure relief of 30 or 60 seconds are shown with loads of 0.4 or 0.5 N. It is noted that the 60 second pressure relief allows more time for the tissue to return to its "normal" position (0 deflection).

DISCUSSION

The primary event leading to skin breakdown is occlusion of blood flow. Although most researchers have emphasized the importance of minimizing the seating interface pressure, we propose that it is the tissue distortion that should be minimized and not just the pressure. Distortion considers the mechanical properties of the tissue as well as the external load. For this paper distortion is represented by a uniaxial deflection of a cylinder of soft tissue. The deflection of this tissue depends on the material stiffness, the applied load, and time (see eq. 1).

Figure 4 shows conceptually the impact of doing pressure relief. Suppose that breakdown begins to occur for the given sample when tissue deflection exceeds 36 mm for greater than 5 minutes. Then either doing a long pressure relief (case B) or having lower applied force (case C) would be safe. However, case A would be at risk for a pressure sore.

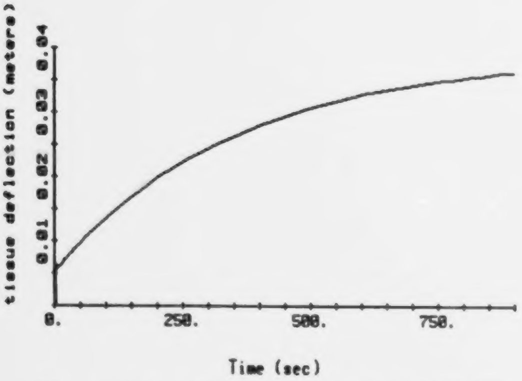

Fig. 3. Skin deflection following application of a constant force of 0.5 N.

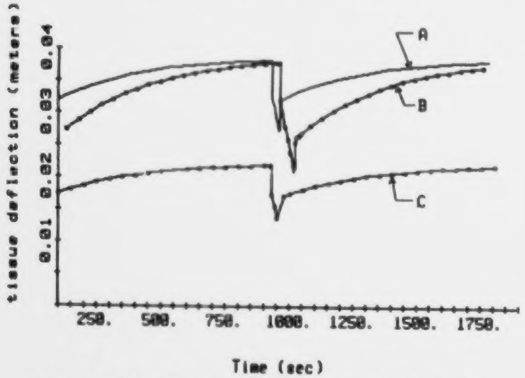

Fig. 4. The effect of performing a pressure relief. Skin deflection has reached near steady state prior to doing the pressure relief.
Curve A - 0.5 N force, 30 second relief.
Curve B - 0.5 N force, 60 second relief.
Curve C - 0.4 N force, 30 second relief.

Tissue breakdown is certainly a dynamic event (i.e. time dependent) and therefore a dynamic analysis is necessary to fully understand the process. The dynamic model presented is simple and has obvious inaccuracies. To create a more accurate representation of the system, experiments need to be designed which will demonstrate certain types of behavior for model validation. In addition, the system needs to be expanded into three dimensions. The present paper is a first step toward understanding the biomechanics of the seating interface dynamics. Mechanical models such as the one presented can provide valuable insight and possibly lead to new methods for evaluating seating systems and preventing pressure sores.

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ADDRESS

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MPI SEATING SYSTEM
TECHNICAL EVOLUTION

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ABSTRACT

The MPI has gone through four phases of design and clinical use over the last 10 years. Approximately 300 systems have been fitted by the University of Tennessee - Rehabilitation Engineering Program (UTREP) and 200 by other programs. This paper documents the system's technical evolution and presents the results of a recent survey exploring the types of wheeled bases used, growth adjustments made, and breakage problems encountered.

SYSTEM DESCRIPTION

The MPI or Modular Plastic Insert, is a seating system developed by the UTREP. One of the first modular systems, it has been designed for use by moderately involved cerebral palsied children who do not have fixed skeletal deformities.

ABS INTERFACE MODEL MK-I (1976-1980)

The initial model used 4 sizes of rolled seats with lateral thigh blocks. There were six back sizes with bilateral bolsters, mild lumbar roll and midline groove for the spine. Accesories included three head supports, and a neckrest, separate foot rests, arm rests, two lap trays, a lap belt and various anterior trunk supports. Seats and backs were pop riveted to ABS interfaces which in turn provided attachment points for mounting in a wheeled base (Fig. 1). The model interfaced with a variety of stroller and wheelchair bases. A measuring chair or simulator was provided to help fit and select components.

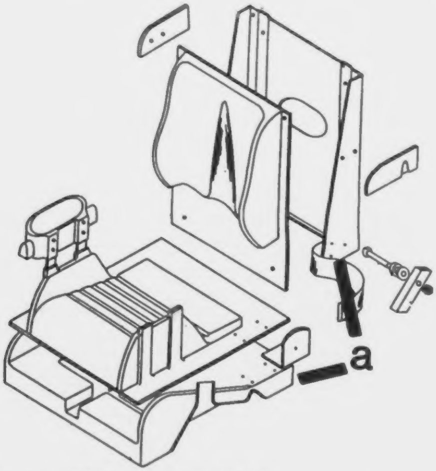

Fig. 1 - ABS Interface Model
(a) Seat & Back ABS Plastic Interfaces

PROBLEMS ENCOUNTERED

A 1978 evaluation at seven rehabilitation centers and local clinical experience with approximately 120 fittings uncovered several problems with this initial design (Platt 1979).

- The unpadded back created pressure areas and was not angle adjustable.
- The headrests were not durable and not adjustable enough.
- The armrests were hard to assemble and prone to breakage.
- The tray mount was not secure.
- The footrests were not durable.

The ABS seat and back interfaces, however, proved to be most troublesome with breakage common after only six months of use. Interfacing with wheeled bases was clumsy and time consuming.

ALUMINUM "U" FRAME INTERFACE MK-II (1980-1983)

In response to the above problems the system components were almost totally redesigned though the well received system concept remained unchanged. An aluminum "U" frame interface replaced the weak and clumsy seat and back plastic interfaces (Figure 2). The telescoping "U" frame allowed easier linear adjustment of the seat and back and a ratchet, a toothed pivot joint, provided angular adjustment between the seat and back. The "U" frame also provided secure mounting for head and footrests; and receptacles for hardware which flexibly mounted the system into wheeled bases. There were five seat and four back sizes which retained the contours of the initial system. In 1981 the revised system was distributed through Medical Equipment Distributors, Inc. (MED).

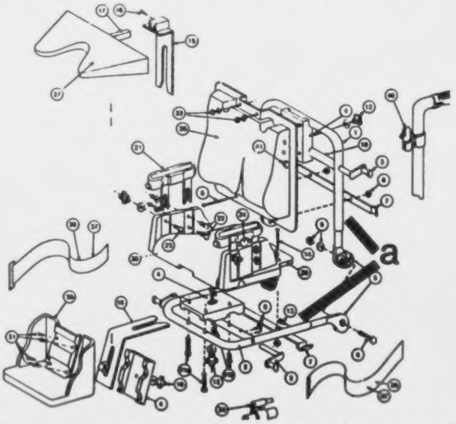

Figure 2 - Aluminum "U" Frame Interface (MK-II)
(a) Seat & Back "U" Frames

PROBLEMS ENCOUNTERED

The "U" frame model was a vast improvement over its virtually all plastic predecessor. Still, several problems showed up in the course of approximately 150 UTREP fittings of the MK-II design.

* The seat plastic cracked.
* The adjustable wheel base mounting hardware loosened.
* The footrests, redesigned as a one piece ABS unit in 2 different sizes, was easily fractured by active users.
* Children with thigh length less than 8" were hard to fit.
* Tray mounting on the system armrests was unstable.

Ongoing revisions resolved the first three problems, but two significant problems which were never satisfactorily resolved were poor quality control and poor parts distribution. Poor quality control resulted in misfit parts and long assembly times (3-5 hours). Constant delays in shipping parts resulted in delays fitting clients.

ALUMINUM "U" FRAME INTERFACE (MK-III) (1984-1985)

The next redesign was prompted by UTREP therapy staff requests for a flat back and flat seat. The back's lumbar roll and spinal groove were eliminated and in their place was a padded flat surface which extended further down providing more support for the lower lumbar region and pelvis. Receptacles for armrests tray mounts were eliminated from the seat bolsters. The back bolsters were made higher (more aggressive) and thinner in profile. The seat's anterior roll was eliminated and front edge tucked under to accommodate tight hamstring users. In addition the dimensions of the seats and backs were changed to better fit typical user body sizes. Previous interference between seat and back bolsters encountered when fitting small children was eliminated. A fixed 90° seat to back joint, an alternative to the angle adjustable ratchet, accommodated very small children with a six inch minimum thigh length. An in-house survey revealed that only 5/75 or 7% of the systems fit between 12/81 and 11/83 had the ratchet set in flexion (3) or extension (2). The largest and rarely used seat size was dropped. The MK-III design was used for approximately 30 UTREP clients only. The ABS footrest was replaced by a reinforced high density polyethelene unit which proved much less prone to cracking. Whenever possible active clients were fit with foot support attached to the wheeled base frame.

PROBLEMS ENCOUNTERED

* Problems with vacuum forming the seat front tuck-under forced dropping this feature. Because clients with knee flexion contractures past 90° were typically fit with custom systems the feature was rarely needed.
* Even though four back sizes were provided the therapists complained that the higher back bolsters, while providing more agressive support, seldom fit snugly enough to provide control yet loosely enough to allow for growth or winter clothes. Width between the bolsters increased in 3/4" increments from the smallest to the largest back sizes.

Former problems of quality control and delays in getting parts were, at least for the UTREP, eventually solved by in house part fabrication and dealing directly with offsite manufacturers of the critical parts such as the "U" frames.

ALUMINUM "U" FRAME INTERFACE MK-IV (C.P. SEAT) (1985 - PRESENT)

The current model (MK-IV), now marketed by Pin Dot Products is the CP Seat. The back module has width and height adjustable bolsters which allows the therapist full flexibility in bolster snugness and height placement (Figure 3).

A great improvement has been made in ease of assembly requiring fewer fasteners. Assembly times have dropped from 3-5 hours down to 1 - 1 1/2 hours. Approximately 30 systems have been fit to date at the UTREP.

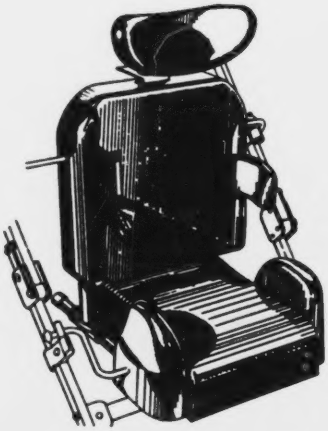

Figure 3 - Aluminum Interface (MK-IV) (CP Seat)

PROBLEMS ENCOUNTERED

The back bolster width range from 7.0" to 9.5" was too limiting. The bolster mounting is now being revised.

RESULTS OF TECHNICAL SURVEY

Fifty four systems representing all four MPI models were randomly selected from approximately 300 total systems for technical review. Records exist concerning the total life span of 23 (43%) systems, 19 (36%) systems are still in use and 11 (21%) lost to follow up. Figure 4 shows users age at the initial fit.

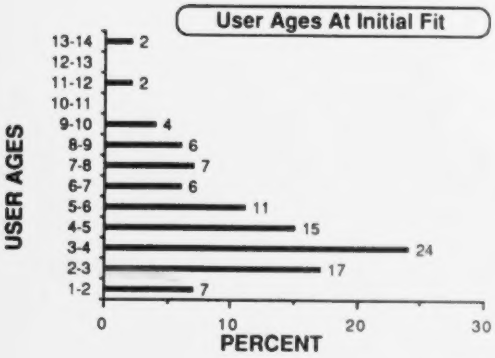

Figure 4 - Age Distribution of Users at the time of initial system fitting.

WHEELED BASES USED

Forty-nine percent of the systems were interfaced to wheelchairs, forty-six percent to McLaren Major Buggies or Pogon Strollers, and four percent to other bases. During the last 3 years larger percentages of wheelchairs are used due in part to requirements for school bus transport safety. Mounting in standard wheelchairs has been the easiest. Mounting in some of the newer ultralight chairs has been difficult. Interfacing, challenging with any seating system, is complicated by the MPI's design when trying to seat the user low enough to self propel.

ADJUSTMENTS AND PARTS REPLACED FOR GROWTH

Forty percent of those systems we have a full use history on were not adjusted or had parts replaced due to growth during their 3.8 years average life span. Thirteen percent were adjusted five times. Overall the average adjustment rate was 0.4 adjustments per system per year or 1.5 per system life span. We suspect that many of those systems which were not adjusted for growth were not reviewed frequently enough. Though we have recommended an initial review within the first 6 months and subsequent annual reviews, many children were not reviewd for 2-4 years. One child who is being reviewed regularly has a growth adjustment rate of 1.2 adjustments per year, or three times the average rate.

Most linear adjustments were in increments of 1 inch. Adjusting the thigh length was the most popular, accounting for a third of all adjustments made. The thigh length was increased 18 times and, interestingly, decreased 5 times. Twenty three percent of the adjustments involved seat to back angle and more commonly, orientation of the system in the wheeled base. Because all linear and angular adjustments require shifting of the interface system, they are very time consuming on many custom seating systems built without adjustment potential in mind. Ten seats and fifteen backs were replaced due to growth. The last model's adjustable back should reduce the number of replacements necessary.

BREAKAGE

Twenty six percent of the systems had broken or loose components. The breakage rate was 0.1 breaks per system per year or 0.4 per system life span. The ABS interface model had a breakage rate twice that of the "U" frame models. Active users, especially those with strong extensor patterns, or constantly in motion exposed several durability problem areas mentioned above. The "U" frame approach, which used the aluminum frame to bear the majority of the stresses reduced plastic breakage. This problem, especially troublesome in the seats, was not solved until the plastic parts were firmly supported by the frame at several points. We found that the ABS plastic, though initially tough and impact resistant eventually fractures at points of stress concentration due to cyclical loading (fatigue fracture).

In addition to reducing the breakage problem, the "U" frame wheelchair attachment method proved to be excellent and has subsequently been used for Foam and Plywood, Bead Seat, Foam-In-Place, and Shapeable Matrix seating systems. The headrest and footrest hardware has also been useful for these other systems.

SUMMARY

The MPI has evolved from a fragile, hard to assemble system to one that is more durable and easy to assemble and adjust. The MK-IV model, the commercial C.P. Seat, can be assembled in less than 1 1/2 hours. Based on past experiences we expect the typical future user to be between two to six years old and to use the system for four years. During this time one to two growth adjustments will be made and possibly one repair required.

ACKNOWLEDGEMENT

The development of the MPI, directed by Douglas A. Hobson, P. Eng., has been an ongoing UTREP project involving many therapists, technicians, and engineers.

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EFFECT OF SEAT ANGLE AND LUMBAR SUPPORT ON SEATED BUTTOCK PRESSURE

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The purpose of this study was to compare the effects of two seat angles with and without a lumbar support on ischial tuberosity pressure. Twenty subjects were seated on an adapted pedobarograph incorporated into an adjustable chair. A TV camera on the underside of the plexiglass seat detected changes in light levels in direct relation to pressure application. The camera output was passed to a computer where the signal was converted to color. Each color was calibrated to represent nine pressure intervals ranging from 0 to over 500 mm of Hg. Pressure contours were recorded before and after seat angle adjustment and lumbar support placement. The computer calculated the area of each color by summing the number of digitized points (pixels). The results demonstrated high test retest reliability for each position (r=.95). There was a significant decrease in the highest pressure intervals when the lumbar support was used in both the upright and reclined positions (p .05).

INTRODUCTION

Pressure sores represent one of the major complications facing disabled individuals, especially those with spinal cord injuries. Zacharkow (20) hypothesized that sitting posture may be a major contributing factor leading to the development of pressure sores.

The incidence of pressure sores as reported by Clark (5) is 21.6 percent for paraplegia and 23.1 percent for quadriplegia. Geisler (9) reports over 4 percent of deaths among the spinal cord injured have been directly attributed to pressure sores. Renal failure (11) is the leading cause of death in the chronic spinal cord injured, and can be the result of chronic skin ulceration (7). The estimated medical cost associated with the healing of a pressure sore ranges from 10,000 to 46,000 dollars. During the first four years following spinal injury, the patient with pressure sores averaged 15,000 dollars a year more in medical costs than those without sores (19).

The ischial pressure sore has been found to be the most prevalent (6,8), and it has been determined that more pressure sores are due to sitting than to the recumbent position.

Kyphotic sitting can eventually lead to asymmetrical sitting postures characterized by spinal scoliosis and pelvic obliquity, factors which appear to be closely associated with uneven sitting pressure distribution and the eventual production of a pressure sore (14, 15). If the normal standing posture (lordosis) is maintained in sitting, advantages may include decreased disc pressure (2), relaxation of the lumbar paraspinal muscles (1), prevention of kyphotic and scoliotic spinal deformities with pelvic obliquities (12), improved diaphragmatic breathing (3), and less fatigability with increased comfort (10,19).

Zacharkow (20) recommends a seat to backrest angle of 95 degrees, and suggests this posture facilitates sitting balance and functional independence. Because of the serious consequences resulting from a pressure sore, a sitting posture that potentially enhances the development of an ischial sore could never be justified regardless of other conceivable benefits of this posture.

The purpose of this study was to compare the effects of two seat angles (0 and 10 degrees) with and without a lumbar support on the area of highest buttock pressure (ischial tuberosity) at a fixed 95 degree seat to backrest angle.

MATERIALS AND METHODS

Subjects

Five males and fifteen females were included in this study. Subjects were volunteers meeting the following criteria: 1) able bodied; 2) 20 to 59 years old; 3) no history of low back pain in last 6 months; 4) no evidence of scoliosis; 5) normal spine extension by visual inspection in standing backward bending. The mean age was 32.65 years, mean weight 130.8 (±18.6) pounds, and a mean height 66.6 (±3.45) inches.

Instrumentation

The ischiobarograph (17,21) for measuring sitting pressure consists of an 18 by 18 inch plexiglass sheet (½ inch thick) incorporated into a seating device with adjustable seat, backrest angle and adjustable footrests. The device is instrumented with hand jacks so that the entire device can be tilted while the subject is in place, therefore changing the seat angle. Two domestic 13 W flourescent tubes 21 inches long are located at the optically polished edges and covered with a dense cloth to prevent stray lighting. An angled mirror (45 degrees) within the box deflects the optical path of the detecting surface to a horizontally mounted television camera. The output from the camera passes to a video analyzer board residing in one of the expansion slots of a personal computer equipped with a dual disc drive, and color monitor. This analyzer contains a microcomputer which converts the video signal into 16 colors, each corresponding to different grey scale light levels, and is controlled by menu driven software. Samples of buttock pressures were taken at a rate of two pictures per second. The seated pressure pattern was plotted on the color monitor and stored on floppy diskette. The computer calculated the area by summing the number of digitized points, called pixels, comprising each color region.

Calibration of the barograph was achieved by using an air pressure system to allow for equal pressure loading. The pressure applicator was

2.5 cm. in diameter and pressurized from a compressed air cylinder with the reading noted from a pressure transducer. Calibration was done by noting the pressure transducer reading in relation to the change-over level from one color band to the next. Although the system had the capabilities for 16 pressure levels, some levels (colors) were combined to form larger pressure intervals. The pressure intervals consisted of the following: 1) greater than 500 mm Hg, 2) greater than 450 mm Hg, 3) greater than 400 mm Hg, 4) greater than 325 mm Hg, 5) greater than 225 mm Hg, 6) greater than 100 mm Hg, 7) greater than 50 mm Hg, 8) greater than 0 mm Hg, and 9) 0 mm Hg. The color monitor was made up of 256,000 pixels. A window incorporating the concentric rings of highest pressures was utilized allowing area calculations to be restricted to this window.

The lumbar support consisted of 1.75 inches of firm polyurethane foam (durafloat II-10 pound density and 140 pound indention load deflection), and a less dense 1.5 inch polyethelene foam (4 poung density and 70 pound indention load deflection). The support was 4 inches in height, 15 inches long, and 3.25 inches thick uncompressed.

Procedure

Although four positions were being tested, to adequately determine the reliability and to eliminate any ordering effect of the test positions, a series of nine positions were evaluated for each subject. The pressure contours for each of the nine positions was recorded and stored on diskette 45 seconds after the position was assumed.

The starting position began when the seat to backrest angle was fixed at 95 degrees with the seat being horizontal and the backrest 5 degrees reclined. The feet were supported by an adjustable footrest so the knees were at an 80 degree angle and the thighs (femur) parallel with the seat surface. The ankles were maintained at 100 degrees using the tibia and fifth metatarsal as landmarks for goniometric measures.

The initial posture of the subject (position 1) was defined as the subject having his/her sacrum positioned at the back of the seat and in contact with the chair back, eyes fixed horizontally, and hands and forearms resting on the thighs. The actual seat to backrest angle and footrest placement remained constant for the eight remaining test positions, and subjects were instructed not to move.

Position 2 involved raising the front of the seating device so that the seat surface was ten degrees reclined and the backrest 15 degrees reclined (seat to backrest angle constant 95 degrees).

Position 3 involved returning the seat angle to the horizontal position similar to position 1.

Position 4 involved having the subject roll the upper trunk forward just enough to allow placement of the lumbar pad so that the lowest edge was approximately one-half inch below the posterior iliac crests (20).

Position 5 involved raising the front of the seating device ten degrees with the lumbar support in place.

Position 6 returned the seat angle to the horizontal position (position 4).

Position 7 again elevated the front of the device ten degrees (position 5).

Position 8 involved removing the lumbar support while maintaining the reclined seat position.

Position 9 repeated position 1 by returning the angle of the seat to horizontal.

METHODS OF ANALYSIS

Reliability of repeated positions for the means of two measurements was made using an intra-class correlation. The positions correlated for each pressure interval were as follows: 1:3, 1:9, 2:8, 4:6, 5:7. A Z-transformation was performed for each correlation coefficient and combined into one coefficient.

Data was descriptively analysed and graphed as a percent decrease in pressure area normalized to position one.

Two sided paired t-tests (16) with a Bonferroni adjustment was completed simultaneously to compare position 1:2, 1:4, 2:5, 4:5, 1:5, and 2:4. A two-by-two ANOVA was completed to compare the repeated measures of all nine positions.

RESULTS

The overall intra-class correlation coefficient for all repeated test positions of all pressure levels was .95, indicating very high reproducibility.

Figure 1 demonstrates the mean decrease in pressure area compared to the starting position (position 1) at each pressure interval. Note the large percent decrease of the high pressure areas greater than 500 mm of Hg with the use of a lumbar support in both the ten degree reclined and upright positions. Without a lumbar support, there is approximately a 10 percent decrease by merely reclining the seat angle ten degrees. The decrease in the high pressure areas is in combination with an increase of the low pressure areas most noted at 100 mm of Hg and less.

The ANOVA and the multiple t-tests with adjustments showed significant ($p < .05$) decreases in the pressure areas in intervals greater than 100 mm of Hg. There was also a significant increase ($P < .05$) in the pressure area for intervals below 100 mm of Hg. The 0 pressure interval demonstrated a significant decrease ($p < .05$) in the area where no pressure was applied, which indicates that the seated pressure is being applied over a greater area. There was no significant difference between the upright and the reclined positions without the lumbar support. There was also no significant difference between the upright with a lumbar support and reclined with a lumbar support. There was a significant decrease ($p < .05$) in pressure area between the positions with a lumbar support (reclined and upright) and the reclined without a lumbar support among the pressure intervals greater than 100 mm of Hg. There was also a significant increase of the area in the pressure interval less than 100 mm of Hg when comparing positions using a lumbar support with the reclined position not using a lumbar support.

DISCUSSION

The high pressure isobars were always reduced significantly with the use of a lumbar support. The fact that the ten degree recline did not significantly alter the effect of the lumbar support can be very important to the disabled population. Without paraspinal musculature, sitting balance is altered in a wheelchair, and the use of a lumbar support is virtually impossible because of the inability to maintain balance and conform to the support. This ten degree recline is often necessary to allow the disabled population to balance and use a lumbar support.

The fact that a lumbar support reduces the highest pressure areas was demonstrated by Shields (21) using a less refined system for measurement (three pressure levels). This study, in using nine pressure levels, allowed for closer study of the lumbar support effects on the highest pressure areas, as well as the effects of a ten degree recline interacting with the lumbar support.

Limitations of this study are related to the pressure measurements taken on a hard surface. The absolute values of the pressures are of little importance in this study, but the relative effects of certain postures on highest buttock pressures can shed light on optimal chair design. Use of an adequate cushion in conjunction with these defined postures may prove to be the most optimal means of prevention of pressure sores in the high risk pressure sore population.

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THE COMPARISON OF SUPPORT INTERFACE PRESSURE MEASURING SYSTEMS

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ABSTRACT

A series of pressure measurements were carried out by two independent groups to establish the agreement between three common interface pressure measuring systems. Using a clinically desirable protocol, 1080 independent pressure measurements were analyzed by linear regression to establish correlation, standard deviation and values of variance between transducer pairs and two observers.

INTRODUCTION

The importance of pressure evaluation in clinical assessment of body support systems is now clearly recognized and used in many of the progressive hospitals and rehabilitation institutions. Among the several transducers in use the null-balance electropneumatic sensors appear to be most popular. The transducers used in pressure evaluations are inconsistent, the measurement technology is poorly defined and variable among the institutions. The variation in measurement techniques leads to disagreeing results and inefficient measurements.

The factors effecting the results of pressure evaluation are many, but the important ones are:

A. the transducer size and material
B. load shape and its interaction with the support material
C. the method of endpoint detection
D. the uniformity of the measurement technique

This work was directed to establish a consistent support interface measurement technique applicable to seating prescription and design. In previous work, the performance of three electropneumatic pressure transducers have been described by spot, plane and curved surface load calibration(1).

AIMS

The objective of the work was to establish the agreement among the three most common pressure evaluating system using a clinically acceptable protocol. These results may subsequently serve to develop correction factors for shape, size and material variations among transducers.

METHODS

Interface pressures were measured by the Scimedic(2), TIRR(3) and Gaymar (PSP-1, Gaymar Industries, Inc., Buffalo, NY) pressure transducers on ten normal volunteers by two experienced, independent observers at the Cleveland Clinic and the Gaymar Medical Research Laboratory, respectively. The standard TIRR Pressure evaluation pad was parallel interfaced to a digital computer(5) and currently used with an IBM AT personal computer and a DT2817 interface board. The subjects were tested in the sitting and recumbent (side lying and supine) postural positions using all three transducers on three support systems successively. In the sitting position the pressure under the coccyx, ischial tuberosities and trochanters and thighs were measured; while in the recumbent positions the trochanteric and sacral pressures were observed. All measurements were repeated three times by each observer by relocating the transducers each time. All pressure values were recorded, but only the highest of each three observations was used for the statistical analysis and calculations. The support materials were blue "egg crate" foam, high resiliency 3" thick polyurethane foam and the constant pressure "Sof-care" air inflation system (SC804, Gaymar Industries, Inc., Buffalo, NY). The support materials were made into seat cushion and bed cushion size pads for the measurement of contact pressures. Recumbent pressures on the egg crate foam were measured on both single and double layers, but sitting pressures were measured only on double layers of this foam.

The weight bearing characteristics of the supports were established by the Indentation Load Deflection (ILD) test at 25% compression using an 8" diameter, 3/4" thick, smooth plywood indentor with an MTS 858 Bionix Test System using the following procedure:

1. The support to be tested was placed on an 18" X 18" X 3/4" plywood surface.
2. The indentor was lowered into the support until a one pound load was applied.
3. The thickness of the support at this time was entered into a program and the indentor movement action started.
4. At 75% of the support thickness, the indentor motion was stopped and the load on the indentor was measured after one minute.
5. The resulting load was reported as the 25% ILD.

RESULTS

Interface pressures were measured up to 100mmHg to minimize hysteresis effects in the vinyl transducer bags. The lower limit of the measurements was set by the Scimedic transducer which did not provide readings less than 20mmHg.

Linear regression analysis was performed on data collected at the Cleveland Clinic, at Gaymar Industries, and on the combined data from both locations. At each location, pressure values collected from ten subjects using one instrument were regressed on values measured on the same ten subjects with a second instrument. For the combined data, the regression was repeated using all twenty subjects.

Table 1 shows the correlation equations for the interface pressures measured by the Gaymar (G), the Scimedic (S) and the TIRR (T) transducers in mmHg units using the separate data from each laboratory and the combined data. Also shown are the Pearson's product moment correlation coefficients (r) with a significance of 0.001. To estimate the error in the measurements, the standard deviation (S.D.) of the dependent variable is also displayed. These results on Table 1 show highly significant, strong correlation between the outputs of the transducers for 1080 independent pressure measurements by four observers in the range of 20 to 100 mmHg. Plots for each regression of the combined data are shown in Figure 1.

TABLE 1

Regression Equations of Transducer Outputs

Transducers	Equations	S.D.	r
Combined Data:			
Scimedic vs Gaymar	S = 0.92 G + 9.96	±11.3	0.887
TIRR vs Scimedic	T = 0.86 S + 3.30	±12.2	0.846
TIRR vs Gaymar	T = 0.85 G + 0.37	±14.8	0.801
Gaymar Data:			
Scimedic vs. Gaymar	S = 0.96 G + 8.17	±11.7	0.883
TIRR vs Scimedic	T = 0.93 S + 2.03	±13.8	0.861
TIRR vs Gaymar	T = 0.96 G + 6.66	±15.7	0.816
Cleveland Clinic Data:			
Scimedic vs Gaymar	S = 0.88 G + 11.65	±10.8	0.892
TIRR vs Scimedic	T = 0.79 S + 4.94	±12.0	0.841
TIRR vs Gaymar	T = 0.75 G + 11.64	±13.1	0.806

The regression of transducer outputs as a function of support type are shown on Table 2 using combined data from both labs. On any of the support materials, the corelations are always the highest between Scimedic and Gaymar transducers and least between the TIRR and the Gaymar transducers. On the high resiliency HR70 foam, the correlations are nearly the same between Scimedic and Gaymar as between TIRR and Scimedic transducers. The progression of the standard deviations show always the least variance of the Scimedic compared to the Gaymar and highest variance of the TIRR when compared to Gaymar transducer.

Fig. 1 Regression Plots.

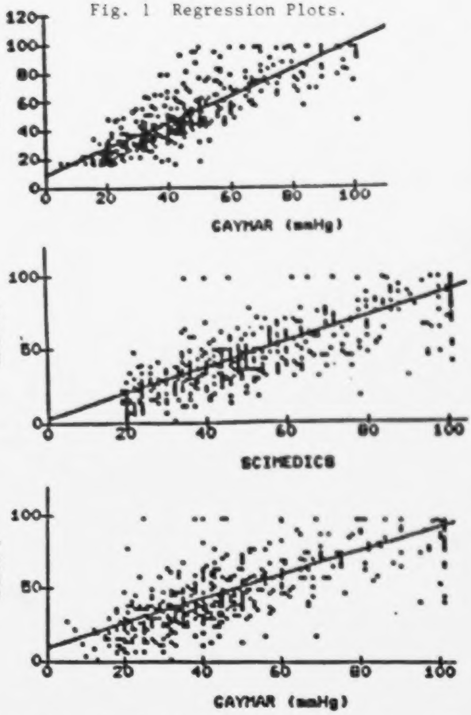

TABLE 2

Regression of Transducer Outputs
as a Function of Support Type

Transducers	Equations	S.D.	r
Double Eggcrate			
Scimedic vs Gaymar	S = 0.95 G +10.96	±10.59	0.923
TIRR vs Scimedic	T = 0.90 S + 1.93	±16.47	0.832
TIRR vs Gaymar	T = 0.86 G +10.87	±18.71	0.776
HR70 Foam			
Scimedic vs. Gaymar	S = 0.86 G +12.28	±10.66	0.899
TIRR vs Scimedic	T = 0.94 S - 2.22	±10.91	0.903
TIRR vs Gaymar	T = 0.89 G + 5.71	±12.03	0.881
Sof-care			
Scimedic vs Gaymar	S = 1.00 G + 5.66	±12.06	0.799
TIRR vs Scimedic	T = 0.66 S +12.91	±12.22	0.737
TIRR vs Gaymar	T = 0.77 G +12.054	±13.20	0.684

Sig r = 0.0001

The precision of the pressure measurements were also studied by two different observers (OB1 and OB2) using the Gaymar and Scimedic transducers, the same subject, the same three supports and the same procedure. This correlation is shown in Equation 1 with the standard deviation of the dependent variable, the correlation coefficient and its significance

EQ. 1

$$OB2 = 0.86(OB1) + 5.96 \qquad S.D. = \pm 11.92$$
$$r = 0.890 \qquad Sig\ r = 0.001$$

Collectively, these results show a 10 to 15 mmHg variation in the indicated pressures between the transducers and between the two observers using the same measurement procedures.

On Table 3, the ILD values are shown for 25% compression of the support cushions. All supports including the air inflated supports were measured using exactly the same technique. Since near the end of the experiments an age related discoloration of the HR70 foam was seen, this cushion was remeasured for ILD. The results show a 10% decrease in ILD over the two months duration of the experiments. These results are included for a quantitative comparison of the cushions and their support characteristics.

TABLE 3

ASTM standard ILD values at 25% compression

8" diameter indentor; each value is the maximum of three successive measurements

	lbs
Sof-care seat cushion	3.57
Single Eggcrate	12.14
Double Eggcrate	12.84
Sof-care bed cushion	24.79
HR-70 foam (used)	80.74
HR-70 foam (new)	89.33

SUMMARY

All transducers tested behaved reliably and correlated well to a significant degree. When the measured pressure distributions were examined for correlations among transducers, the standard deviations were 10 to 15mmHg, while the standard deviation between two skilled observers fell to the middle of that range at ±12mmHg. These results suggest the level of reproducibility of pressure measurement by skilled observers in a clinical environment.

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548

AN ADAPTABLE MICROCOMPUTER BASED CONTROLLER FOR ELECTRIC WHEELCHAIRS

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ABSTRACT

A microcomputer based optimal control system for electric wheelchairs is presented. As the weight of a wheelchair is generally small compared to that of a user, the user's weight can have a tremendous impact on the dynamics of the wheelchair. The velocity feedback controller presented here was designed to give an optimal response for all users by incorporating a measure of the individual user's weight into the control algorithm. This allows optimal control of the motor velocities while assuring the constant stability of the system. Control of the system is managed by a modified Proportional-Integral-Derivative (PID) controller and the adaptability is handled by use of variable structure control. Experimental results are presented.

INTRODUCTION

Of the many external variables affecting the control of an electric wheelchair, the weight of the individual user was found to have the greatest impact [1]. This fact and automatic velocity control are seldom incorporated into commercial wheelchair controllers. A Z80 based velocity feedback controller has been designed that can give an optimal response for users of all weights. A software algorithm was implemented that incorporates a measure of the user's weight into the determination of the coefficients for the control parameters.

The adaptable controller presented here is a modified version of the controller designed by Johnson [1,2,3]. The designed system was implemented in an electric wheelchair and its response tested in the field. The range of loading conditions associated with a control equation is referred to as a *region*. Johnson has shown [1] that the number of regions needed for electric wheelchair control can be limited to four while maintaining system performance to within ten percent of optimal. As conditions vary from one region to another, the system selects the new control equation from memory, thus preserving acceptable system performance.

In his tests of the individual controller regions, Schwab [3,4] showed that each region maintained adequate performance for a wide range of loading conditions. These results engendered the idea of using the variable structure controller in an electric wheelchair, but making it manually adaptable rather than self-adaptive. As the exact region of operation is primarily dependent on the load inertia, which in turn is proportional to the user's weight, the proper region of operation can be estimated and set in software with the assurance of adequate system performance.

SYSTEM SOFTWARE

Control Strategy Implementation

The modified PID controller used in this control system required four equations, one for each region and each containing three terms. These three terms are each of the three control parameters (proportional, integral, and derivative terms) modified by a calculated coefficient. The first of these terms, the proportional term, is taken directly from the actual motor velocity. The second term is the integral term. At each sample time the desired motor velocity is subtracted from the actual and this difference is summed with all past sample errors, forming a quantized error integral q. The third term, being the derivative of the actual velocity, represents the acceleration of the motor. It is obtained by calculating the difference between the current velocity and the last sampled velocity and dividing by the elapsed time since that last sample, i.e. the sampling time.

The parameter coefficients for each of the control equations were derived in [1]. The final control equations used for the complete control of the wheelchair are of the form

$$e_a = -(c_1 \times \omega_l + c_2 \times q + c_3 \times \omega_{l_p}) \qquad (1)$$

with different numerical values for the coefficients in the four regions.

Programming Outline

The software developed for the adaptable controller was coded partly in Fortran-80 and partly in Z-80 assembly language; the primary control routines were written in Fortran, and all input and output operations were handled by assembly. The basic programming flow is shown in Fig. 1.

SYSTEM HARDWARE

A Zilog Z80 processor/STD bus system was used as the basis of the control system hardware. The electrical system is made up of four distinct subdivisions. The primary section is the STD bus rack (microcomputer), and it contains all the digital processing components and the input/output circuitry connecting it to the other three sections (see Fig. 2). The other sections are: the joystick, to provide the desired signals for the controller; the incremental shaft encoders, to provide information on the actual wheelchair status; and the pulse width modulator (PWM) which converts the controller output into a variable DC voltage to drive the motors.

The processing system was completely contained in three STD bus cards: the processor card, the power supply card, and the input/output card. The processor card is a CPU-2+ Z80B processor, counter/timer card containing a 6-MHz Z80B microprocessor and a Z80B Counter/Timer Chip (CTC) with four independent 16-bit channels. The 6 memory sockets included on the CPU card proved sufficient to contain all the RAM and ROM necessary for operation of the system. The power supply board converts the 24V battery voltage to the voltages required by the microcomputer system. The third and final board required for system operation is the input/output board.

Optical Shaft Encoders

Modular Shaft Encoders were used to gauge the actual motor velocities. These encoders consist of a slotted disc/hub assembly that mounts to the motor shaft, enclosed by a photohead assembly mounted onto the motor housing and sealed to prevent soiling. Each encoder produces two frequency signals with a phase quadrature of approximately 90 degrees. This allows for motor velocity information to be obtained from one channel as the frequency of the output waveform is proportional to the motor speed, and also for motor directional information to be extracted from the phase difference between the two channels.

TESTING AND RESULTS

Throughout the course of construction and testing of the adaptable controller, several factors were identified as being important to the control of the wheelchair. The major factors were the sampling time and the integral state error. Also presented are the analysis techniques used to study the system performance, specifically data plots and stability analyses.

Data Collection Analysis

The goal behind the data collection was to gain an understanding of the effects of certain variables in the control algorithm. This was accomplished by plotting sets of system response data. Each set studied the effects of one variable by testing the step response of the system for a range of values of that variable while holding all other things constant. Three variables in all were tested in this manner; the effects of varying the region number was the original objective, and this soon led to tests using differing loads and terrains.

Region and Weight Variation. The step response of the system was tested with a 55 msec sampling time for all four regions for each of four user weights: 40, 125, 180, and 260 pounds (18, 57, 82, and 118 kilograms). The regions in order of increasing user weight are 3, 1, 4, and then 2.

The best left motor response for a 180 pound (82 kg) user, region 4, is shown in Fig. 3. This agrees with the proper theoretical region. Region 3, designed for the lightest of users, had a large peak overshoot (~26%) and a long settling time. Region 1 showed an improved response over region 3, yet still had a peak overshoot large enough to be felt by the user. The region "expecting" the heaviest of users, region 2, showed continued overshoot in the response. In view of the other region responses, one would expect this region to be noticeably overdamped, yet from a logical point of view this response is expected. The control coefficients are adjusted to calculate a response for a much heavier user. That calculated output, when received by a system much lighter than expected, will cause the wheelchair to overreact. Each overreaction is *corrected* by another signal again calculated for a heavier user, and this oscillation continues about any non-zero reference signal. To the user, a rapid oscillation such as this is perceived as a vibration similar to running on rough terrain.

Tests identical to these were run with users of several other weights, and the best responses represented coincidence of user weight and region number, thus validating the use of the derived control equations for the regions.

Terrain Variation. The system was tested for its response and speed control while moving both up and down a ramp of the type used by handicapped persons for constant region 4 operation with a 180 pound (82 kg) test subject and a 55 msec sampling time. Recall that this is the proper region of operation for these conditions. The ramp used held a constant slope of about 4.3° and connected to a length of level ground at both ends. This was desired as it gave the wheelchair time to get up to a normal level-ground speed before hitting the ramp, and time to recover back to this speed after completing it.

The results of these tests show that the controller maintained the desired speed quite well. The down-ramp test results are shown in Fig. 4. Here the wheelchair speed first increases to the desired value, then spikes slightly high as the ramp is encountered. The desired speed is then quickly recovered and maintained down the ramp, dipping only slightly when level ground is again reached. In the up-ramp test a very similar response is obtained. The desired speed is closely maintained except for small fluctuations corresponding to the beginning and end of the ramp.

Overall, the control system responded very rapidly to changes in the terrain, with any sudden disturbances being quickly detected and corrected for. Although this test was not performed using a commercial "controller" the bench testing conducted by Schwab [4] indicates that their performance would not match that of the adaptable controller.

Sampling Time and the Integral State Error Problem

The effect of the sampling time on stability and system response was analyzed in detail [5,6]. A 55 msec sampling time was chosen as giving the best system response and for this reason was used in all other tests in which the sampling time is held constant.

The integral state error is the sum of all past sampled differences between the actual and desired speed. When the control system encounters any set of conditions to which it cannot properly respond, this error term builds up. In order to avoid problems caused by integral state build-up, the maximum speed of the wheelchair was limited so that the output signal can never exceed the capability of the motors even under conditions of heavy loading or ramp climbing. In addition, an instruction was added to the program to set the integral state error to zero any time at which both the desired and actual velocities are zero. In this way, if the wheelchair gets stuck against a curb and the user tries to moves back, the joystick passes through the center position and the error immediately becomes equal to zero.

CONCLUSIONS

The purpose of this work was to develop and implement an adaptable digital controller for an electric wheelchair by modifying a theoretical self-adaptable controller. The hardware and software necessary for such a system was developed, installed in an electric wheelchair, and tested for its response and control.

The results showed that the system had an exceptionally fast response time with near-optimal performance when adjusted correctly, yet the high speed of the response sometimes led to difficulty in maneuvering the wheelchair in an elegant and graceful manner. It was found that the mapping of the joystick space had a sizable effect on the response and control. Many different tactics were employed in the study of these effects, and it was decided that there is much room for further study in this area. The issue of the sampling time was also addressed, and it was found that, for the particular coefficients of the control parameters used, a sampling time of close to 55 msec gave the most stable and effective control.

The only major problem encountered with the control system in this work was the tendency of the integral state to amass extensive amounts of error. This problem was dealt with in a practical way that minimized the possibility of it ever affecting the control of the system.

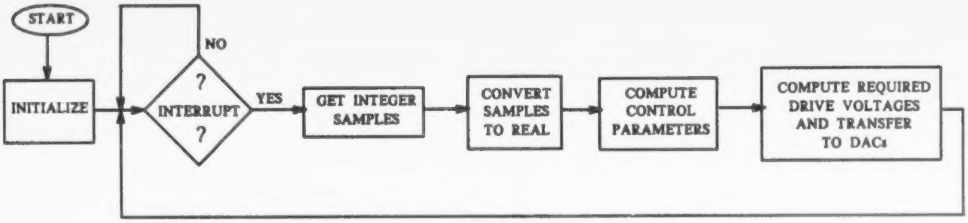
START
INITIALIZE
NO
?
INTERRUPT
?
YES
GET INTEGER SAMPLES
CONVERT SAMPLES TO REAL
COMPUTE CONTROL PARAMETERS
COMPUTE REQUIRED DRIVE VOLTAGES AND TRANSFER TO DACs

Figure 1: Program Flowchart for the Control Algorithm

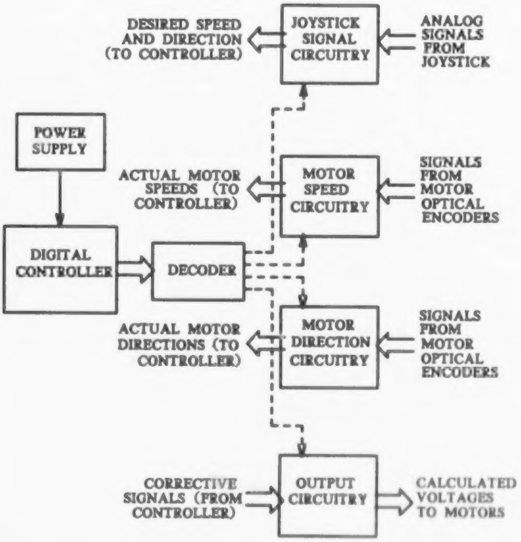
DESIRED SPEED AND DIRECTION (TO CONTROLLER)
JOYSTICK SIGNAL CIRCUITRY
ANALOG SIGNALS FROM JOYSTICK
POWER SUPPLY
ACTUAL MOTOR SPEEDS (TO CONTROLLER)
MOTOR SPEED CIRCUITRY
SIGNALS FROM MOTOR OPTICAL ENCODERS
DIGITAL CONTROLLER
DECODER
ACTUAL MOTOR DIRECTIONS (TO CONTROLLER)
MOTOR DIRECTION CIRCUITRY
SIGNALS FROM MOTOR OPTICAL ENCODERS
CORRECTIVE SIGNALS (FROM CONTROLLER)
OUTPUT CIRCUITRY
CALCULATED VOLTAGES TO MOTORS

Figure 2: Microprocessor System Block Diagram

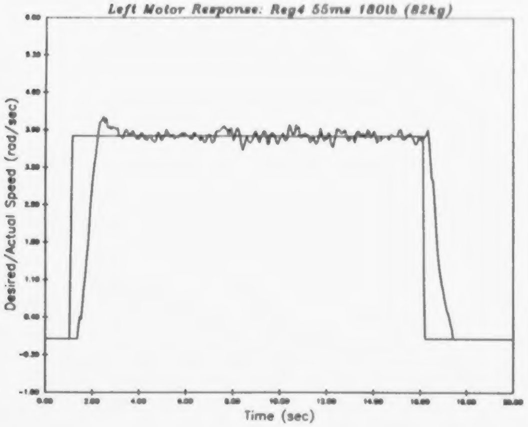

Figure 3: Left Motor Responses for a 180-pound User

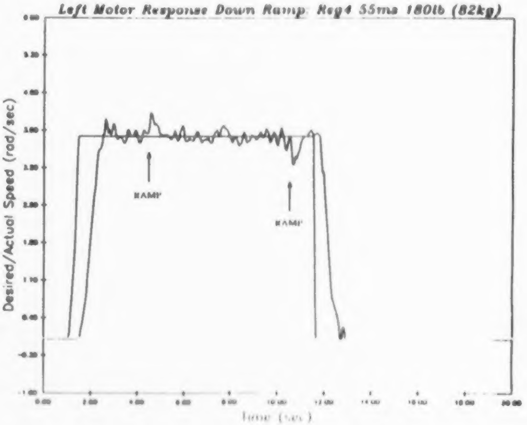

Figure 4: Results of the Down-Ramp Test

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A UNIVERSAL WHEELCHAIR FEEDBACK CONTROLLER

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ABSTRACT

Commercial power mobility aids are generally developed with a particular control system directed towards the major population of disabled users. The most frequently encountered commercial interface is the proportional joystick which requires sufficient user dexterity for the combined control of speed and direction. With more physical involvement associated with a disability the commercial interfacing options are very limited since the interface power control system has usually been dedicated to one particular interface. In our experience, more physically involved clients tend to benefit to a greater degree from more sophisticated interface power controls(5) since the well designated controller can compensate for the client's limited dexterity and reaction time.

INTRODUCTION

A unique wheelchair controller was developed, that can interchangeably respond to both proportional and digital control signals (1,4). The controller incorporates a motor speed control loop which behaves in a fashion similar to cruise controls in modern automobiles and automatically compensates for environmental factors such as sidewalk slant, varying terrain and torque demands.

DEVELOPMENTS TO DATE

Input Circuitry

For the clinician's convenience, the input circuitry of the controller was designed in such a manner that it automatically recognizes the type of interface being connected to it and selects the appropriate decoding strategy. There is also a safety feature built into the controller. In case of a breakdown in the proportional joystick wiring, the input circuitry automatically switches to the digital input mode preventing unpredictable operation of the wheelchair. Priority has been given to the proportional input mode, if both proportional and digital interfaces are connected at the same time. Scaling and amplifying circuitry was implemented in the design to suit the variety of proportional input signal ranges commercially available. All the digital input lines provide 50 msec debouncing and are active low with 5k internal debounce circuit pull-up resistors. Independent internal adjustments of Forward and Reverse speeds have been provided. The digital circuitry was designed for "T" and "X" type gated or ungated digital interfaces. Separate connectors for digital and proportional inputs are mounted on the side panel of the controller's enclosure. The digital input connector is a 9 pin "D" type connected in na format similar to that used in Fortress Commander and E & J Omni-Pilot digital interface adapters. A proportional input connector could be any connector type having a minimum of 10 contacts. Both connectors have to be mechanically durable and able to withstand numerous insertions for situations where the interface is frequently removed for transfers. The acceleration and deceleration rates are easily adjustable by user accessible controls. Maximum values of these rates are limited by the performance of the wheelchair, but the controller internally limits this to 2 m/s2, set by ISO (International Standards Organization). Another feature of the input section is a one-switch, three-channel scanning system developed to provide following functions: power OFF; power ON - Low speed; power ON - HIGH speed. Any momentary active low switch can be used. A visual display provides instantaneous feedback of the selected mode. Both LO and HI speeds are separately adjusted and the ranges overlap in adjustment so that it is possible to set them at the same speeds.

BEMF Speed Control Circuitry

In order to control the speed of the wheelchair motors in a closed loop fashion it is necessary to determine the intended and actual speed of the motor. External speed transducers could be provided to sense motor speed but the mounting of the transducers to various wheelchairs would not be standard or economical. Alternatively, the back electromotive force (BEMF) generated by the permanent magnet motor is proportional to the angular velocity of the motor's shaft and can be used in closed loop speed control. The controller uses a closed loop pulse width modulation circuit (6) which produces an analogue error signal proportional to the difference between the selected speed and the BEMF signal from the motor. The error signal modulates two bidirectional pulse train outputs in proportion to its amplitude and polarity. An analogue data seltor is used to direct the modulator's signals to the appropriate inputs of the MOSFET power bridge, and thereby derive the desired response from the motor.

MOSFET Power Bridge Circuit

For the past many years bipolar power transistors have been used as motor drivers in wheelchair applications. Combinations of NPN and PNP transistors are used in power stages of most wheelchair controllers currently available on the market. The bipolar exhibits the ON voltage characteristic which is fairly stable at lower currents but drastically increases, in a non-linear fashion, at the current levels approaching the maximum ratings of the transistor.

In the last decade new power switching devices, MOSFET transistors have been introduced. These transistors are now available in tens and hundreds of ampere ranges and the prices have dropped significantly in the past several months. The MOSFET exhibits an "ON" resistance characteristic which is basically independent of the current flowing through transistor.

The MOSFET transistors chosen for development of the full "H" configurated power bridge in this project were the IRFZ 40 (51A, 50V) power devices (2,3). Because of the very low ON resistance, this particular transistor requires anywhere from three to ten times less heat sinking than the bipolar transistor of the same current ratings.

OTHER FEATURES

A power bridge was developed to provide more efficient power switching to the wheelchair motors when operated at 20 KHz. The 20 KHz modulation frequency was chosen to reduce audible noise emission from the wheelchair. Closed loop dynamic and static braking circuitry was implemented in the design. The dynamic braking rate depends on the error signal between the ramp down voltage and the motor BEMF signal.

CONCLUSION

One prototype of the designed wheelchair controller has been built and extensive testing of the power stage of the device is planned for the near future. Plans for the future also include the design of microprocessor version of the universal wheelchair controller.

ACKNOWLEDGEMENTS

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MICROCOMPUTER-BASED SCANNING INTERFACE FOR POWERED WHEELCHAIRS

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ABSTRACT

A microcomputer-based scanning interface has been developed at the Hugh MacMillan Medical Centre primarily for mobility control. This interface provides access to the directional inputs of powered wheelchairs for physically handicapped individuals unable to use more direct accessing methods. The interface is easily adaptable with programmable outputs, scanning formats and varying number of interface switch inputs. This paper describes the development, operation and future possibilities of the scanning interface.

INTRODUCTION

A proportional joystick is the most common interface used for controlling a powered wheelchair and provides combined control over speed and direction. The operation of this type of control generally requires good manual dexterity. For individuals who do not possess sufficient motoric control to operate the proportional joystick a microswitch joystick may be used, or the person may require individual switches for each directional movement. The selection and placement of the directional switches would be consistent with the individual's motor patterns and targeting capabilities. The very physically involved individual may not have appropriate switch sites to directly access the directional controls and a method of scanning the directional functions has to be used. Operation of a scanning interface can be controlled with a minimum of one switch but more direct control can be attained as more switches are used.

BACKGROUND

The Interface Program at the Hugh MacMillan Medical Centre (HMMC) has, as an ongoing service, provided specialized control systems for powered wheelchair users. One of these systems has been a two switch scanning interface (Antczak, J. et al 1983) which acts as an input to the HMMC Interface Power Control unit, Fortress Commander or the Everest & Jennings Omni-pilot digital controllers. Several custom versions of this scanning interface were made, dependent upon each individuals needs, needs such as active high and active low outputs, auto-step scan, auto-step scan with reset, single step scan and even one scanning system which required four interface switch inputs. Often other devices, such as communication aids, must also be integrated into the system, again requiring system modification.

With each custom modification many hours of engineering and therapy time are involved. As new clients with more complex needs are assessed for powered mobility the need has been observed for a more adaptable scanning interface able to accommodate many client needs, such as, scanning techniques, various wheelchair types and other technical aids.

MICROCOMPUTER-BASED SCANNING INTERFACE

DesignConsiderations

Input:	From one to three momentary contact switches
Output:	Four direction lines (forward, left, right, reverse), one mode selection line (on/off/speed) and two optional accessory device lines (ex. communication aid). All lines are to be digital and programmable as active high or active low.
Scan Format:	Two scanning formats should be available: 1. A single step scan where each contact with the scan switch steps the display once to the next function, and, 2. A continuous scan where sustained contact with the switch causes the interface to do a continuous sweep of the functions.
Programming:	The final device should be flexible enough to fit a large number of needs while requiring no modifications and being easily programmed to fit those needs by a clinician in the field.

The Design

The device, shown in Figure 1, incorporates a MC1468705R3, forty-pin, single chip microcomputer into its design. This gives the flexibility needed in the device while keeping a small package size by replacing an otherwise large hardware system with software. The algorithms are written into this software for both single step and continuous scan formats. The continuous scan format being broken into two sub-formats:

1) on activation of the designated interface switch the scan of the functions starts where it last left off, and,
2) on activation, the scan resets to the most commonly used function (forward) before starting its scan.

If the scanning interface is used in single switch input mode, a "momentary" contact with the interface switch will initiate a scan response from the microcomputer, this scan response can be single step or continuous. If continuous, the microcomputer will scan through the display till either a function is selected by a "sustained" contact with the interface switch or the list of functions has been scanned three times after which it will stop scanning and wait for the next switch action. The time factor of "momentary" and "sustained" is a function of the selected scan rate. The choice of a scan format is made by setting two small DIP switches on the device circuit board with the appropriate code, while a rotary 10 position switch will vary the scan rate.

The microcomputer has the capability of detecting the number of interface switches connected as inputs and selects the correct algorithm to run under, or a DIP switch can be set to lock a particular mode of operation (one, two or three switch input) in place. In single switch mode the duration of interface switch contact is timed to determine whether the action is meant as a scan command, "momentary" contact, or as a command to implement the current opted function, "sustained" contact. In two switch mode the right most switch, as plugged into the scanner, controls the scan while the left switch implements the current function. When three switches are used the left most switch will select the current function while the remaining two right switches will:

1. either one initiate a scan, or,
2. when a function has been selected by the single left switch, the two right switches will act as left and right trim commands, respectively, to the wheelchair controller.

The two optional outputs for accessory devices may be individually selected to be included in the scan of available functions by setting circuit board DIP switches. Although the display does not include light emitting diodes (LED's) to indicate these functions, the display LED drivers and output pins are present on the circuit board to add these LED's (functions) when needed with out modification to the scanner hardware.

An internal DIP switch also selects the active level, high (+5 volts) or low (ground) of the outputs.

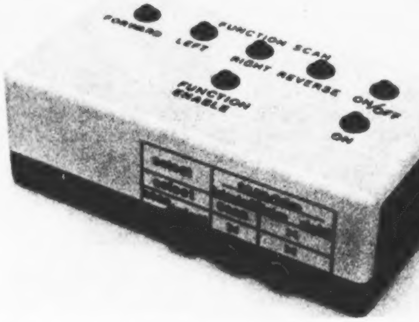

Figure 1: Microcomputer-based Scanning Interface

CONCLUSIONS

A final prototype version of the Microcomputer-based Scanning Interface has been completed. The package size and cost are equivalent to the current two switch scanner while providing additional features, such as, a range of switch inputs, a number of scanning formats and two output formats. The final production version is scheduled to be completed in the next few months. This final version will have several added features to improve the system, they are:

1. A hardware change to make it possible for the micro to detect, on start up, the active levels of the devices plugged into it's outputs, this should eliminate the necessity of knowing whether a wheelchair controller or technical aid requires active high or low inputs.
2. Change the way that scanning speed is selected to make it more continuous and give a larger selection of speeds.
3. Add a ambient light sensor to automatically adjust the LED's brightness level to the surrounding light level.

In all the Microprocessor-based Scanning Interface should prove to be a much more flexible system, able to meet a wider range of needs and abilities and thus be a more cost effective solution when a scanning interface is needed.

ACKNOWLEDGMENTS

We would like to acknowledge the Metropolitan Police Association in their support of the Interface Program and its work.

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SPECIAL WHEELCHAIRS FOR SPECIAL PEOPLE

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ABSTRACT

This paper describes two electric wheelchair projects for clients of the Oklahoma Department of Human Services. The first is an adaptation allowing a severely disabled 27 yr old lady to control an electric wheelchair with two fingers. The second is a powered seat for a youngster born with amelia (total absence of limbs)

Case 1

Tammy is 27 yrs. old, with severe athetiod cerebral palsy. She has been in a residential state school for 24 of those years. Tammy has active finger flexion and extension on one hand and active flexion on the other hand. About a year ago the Occupational Therapist constructed wrist splints for each hand incorporating microswitches, and Tammy uses these to control her Speechpac communicator and other devices.

Tammy's control of an electric wheelchair has been a long time goal of the school staff. Since it was obvious that Tammy is unable to control an electric wheelchair with a standard hand control, other approaches were investigated. Work by Snell (1), detailed a wrist splint used to sense thumb position for discrete wheelchair speed and turn control. Research by Gaddis (2) detailed some options in proportional control including use of linear hall effect sensors and the concept of body mounted controls.

To check whether Tammy had proportional control of her finger movements she was tried on a proportional sensor connected to a bar graph display. A linear hall effect sensor was attached to a hand splint and a magnet attached to her finger. This controlled a multicolored bargraph light display. Tammy was able to stay within any of three ranges by the second training session. From the success of these trials, it was decided to pursue Tammy's proportional control of an electric wheelchair. An interface circuit is under development to convert finger motion to a variable resistance compatible with ABEC wheelchair control units.

Because her control ability is different on each hand, it was decided to have her better finger (left pointing) control forward/reverse, and her worse finger (right pointing) to control direction.

It is anticipated that her left pointing finger will control forward or reverse speed by moving from a partially flexed position. A light spring will return her finger to this midpoint when she relaxes. Turns will be controlled by her right index finger. Because this finger has only active flexion, a light spring will provide extension and a nonlinear circuit will be used, having the transfer function shown as Figure 2.

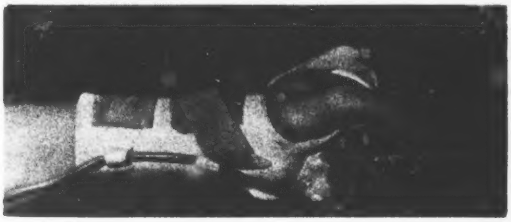

Figure 1 Wrist Splint Incorporating Finger Controlled Microswitch

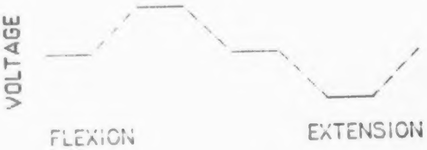

Figure 2, Nonlinear Turn Transfer Function

As illustrated in Figure 3 the speed and turn signals are summed and sent to the ABEC control unit, imitating joystick movements.

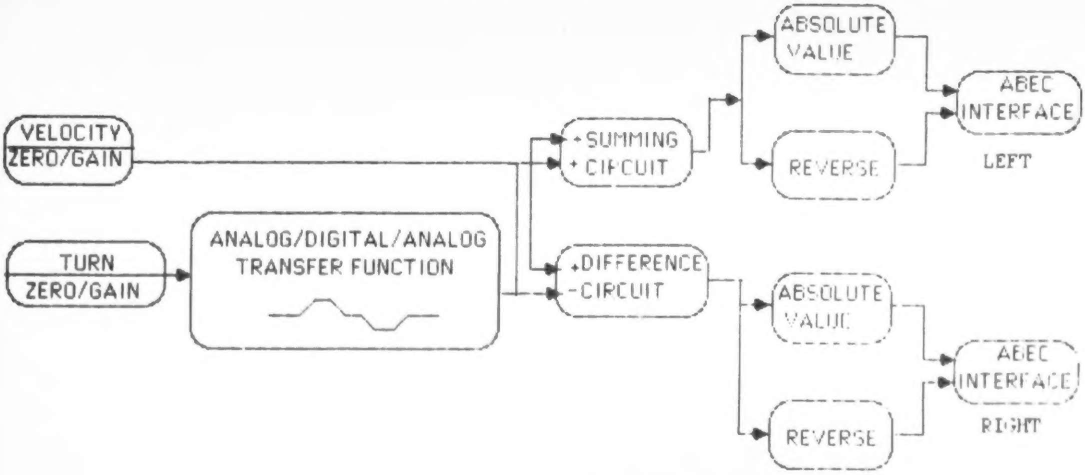
ABSOLUTE VALUE
ABEC INTERFACE
LEFT
VELOCITY
ZERO/GAIN
+ SUMMING
+ CIRCUIT
REVERSE
TURN
ZERO/GAIN
ANALOG/DIGITAL/ANALOG TRANSFER FUNCTION
+DIFFERENCE
-CIRCUIT
ABSOLUTE VALUE
ABEC INTERFACE
REVERSE
RIGHT

Figure 3, Control Block Diagram

FUTURE PLANS

The controller transfer function could be implemented by programming a microprocessor based wheelchair controller such as those developed by Kelly et al (3), or Aylor et al (4). Use of a microcomputer would allow the transfer function between user input and wheelchair response to be individually tailored, or even allow the user to select among several transfer functions dependent on operating enviroment (indoor/outdoor etc.)

Case 2

Jimmy is a ten year old male with amelia. For several years this youngster has controlled an electric wheelchair with his shoulder. At this age he is still growing and trying to be as independent as possible. Due to his muscular build and lack of extremities with which to stabilize him, lifting has become a problem for his mother, sister and teachers. This prompted the ORI staff to develop a wheelchair with powered seat adjustable from floor to table height.

With an adjustable height seat, he can hopefully become independent in transfers as well as providing him more freedom and access to a wider variety of tasks with less help from others.

Figure 4, Powered Seat Wheelchair.

This project was started before the Invacare Turbo became available, (which would have required modification to reach floor level). An ABEC Model 40 was chosen for modification due to its small joystick and control interchangeability with his present wheelchair. A single 35" long, 3/4" threaded rod connected to an ABEC wheelchair motor powers vertical seat motion.

Figure 4 is a front view of the wheelchair under construction.

A wooden seat mockup, on the same scale and design as the final wheelchair seat is shown as Figure 5. This was constructed at ORI and used by the physical therapist to teach Jimmy how to roll into the seat and come to an upright driving position.

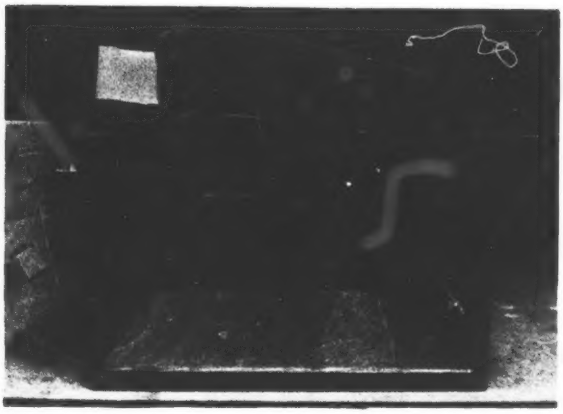

Figure 5, Wooden Seat Mockup

Two breath control tubes will be used. Blowing on tube 1 will raise the seat while sipping will lower it. Blowing on tube 2 will sound a horn, and in the future sipping will operate a powered tray.

Two limit switches systems are used, the first will prevent the motor from turning once the seat is on the floor or reaches a height unsafe because of high center of gravity. A second switch set will prevent wheelchair movement with insufficient ground clearance or high center of gravity.

ACKNOWLEDGEMENT

The authors appreciate the design consultation given by Jim Wolfe of the Oklahoma Childrens Memorial Hospital Biomedical Repair Department.

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DESIGN AND CONTROL OF A CURVILINEAR SYNCHRONOUS WHEELCHAIR

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Abstract. With the intent of highlighting the strength of analytical analysis in low speed fractional horsepower devices, the authors present a study of a linear synchronous motor used as a wheelchair drive. The method of analysis and the development of the controls for the motor are quite general in their applicability. The analytical field computation capitalizes on the extraction of key spatial and constituitive information in the design. Functionals containing the embodiment of this information are used to suggest optimal future designs based on the given power supply constraints. These constraints limit to some extent the efficiency that one might wish to have in the performance criteria. Simple and efficient means of realizing torque and speed control are discussed. Comparisons between the analytical predictions and actual motor data are presented; these comparisons support the viability of the technique fostered in this paper. A discussion of present and future control scenarios is discussed.

INTRODUCTION

An electrical drive is defined to be the combination of an electric motor and the entire electric/electronic control equipment selected to meet the performance (speed-torque) requirements of a load. A variable speed drive is an electrical drive so designed that speed varies over a considerable range as a function of torque [1].

The components of a variable speed drive, or controlled electrical drive, as illustrated in Fig. 1 are (1) the electrical machine, (2) the power source, (3) the power converter, (4) the control equipment, and (5) the mechanical load.

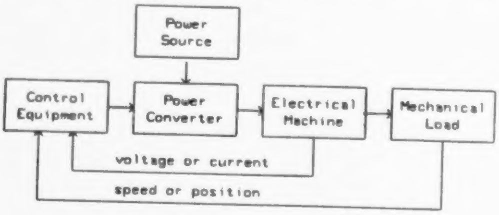

Fig. 1 Components of a Controlled Electrical Drive

Before proceeding with a discussion of the motor, converter, and controller, the characteristics of the source and load need to be specified. A brief sketch of these two components will be presented for the application under investigation - the powered wheelchair.

Because of the mobile nature of powered wheelchairs, deep-cycling batteries are the conventional power source. Typically, the fixed potential DC source consists of two 12 volt batteries.

Powered wheelchairs, most commonly, have two independent drive wheels and passive casters. As is typical with transportation systems, the inertia of the mechanical load (wheelchair and operator) is many times that of the motor itself. The payload is nominally 350 pounds, and performance criteria have been proposed [2]. Some of these situation specific criteria are illustrated in a performance envelope shown in Fig. 2.

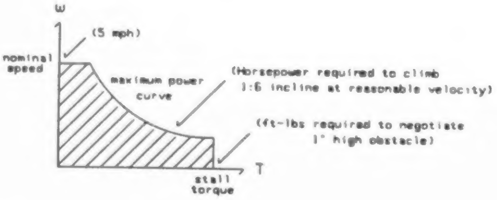

Fig. 2 Speed-Torque Envelope for a Powered Wheel (Standard 20° Wheel, Direct Drive)

The power linkage between the motor and the wheel is realized by a drive belt such as the one used commonly on a car. The reliability of the motor/drive belt interaction is low. Typical efficiencies with a motor and belt system are approximately 20% [2]. Among the stronger motivations behind this work are the following:

(1) A desire to increase the motor drive efficiency to 80 or 90%.
(2) A desire to eliminate the unreliability of the gearing/drive mechanism.

The innovation of this design is fourfold:

(1) It provides high torque at low speeds.
(2) It has a relatively flat torque-speed profile.
(3) It provides a low maintenance, high reliability design.
(4) It improves efficiency by 300-400% over existing motor drives.

The design is promising as an ideal wheelchair motor in that it provides the essential torque, rpm range, and efficiency necessary to a small electric vehicle. The elimination of gears, pulleys, belts, and permanent magnet DC motors provides reliability and durability beyond that realized in the present systems. Closed loop control of wheelchairs with a high efficiency controller in itself provides a vehicle with improved performance parameters [3-5]. This Curvilinear Synchronous Motor (CSM) offers creative design changes to powered wheelchairs.

THE SYNCHRONOUS MOTOR WHEELCHAIR

Of the three motor types (DC, AC induction, and AC synchronous), DC drives have been the standard solution for electromechanical systems requiring variable speed control. This is because DC motors have been able to provide the best speed control with high starting torque.

During the last decade, the field of variable speed drives has experienced rapid expansion with many of the basic concepts having to be re-examined. In particular, electronically switched solid state supplies have produced significant interest in AC motor drives not subject to the limitations of mechanically commutated DC drives [6].

Advances in power electronics (variable frequency, variable voltage power inverters), magnetic materials (rare earth cobalt), angular position measuring devices and signal processing with analog, digital, and microprocessor integrated circuits have made synchronous drives a real alternative to the DC drives that have dominated the field.

By way of realizing some of the goals cited above, we sought a synchronous motor design which incorporated the motor into the wheel itself. The rotor of the wheel is simply a set of magnets radially oriented alternating north-south in the peripheral direction around the wheel. The stator affixed to the chair consists of a three phase winding embedded in an iron powder substrate. Control and torque generation are achieved by altering a three phase excitation of current on the stator winding.

FIELD ANALYSIS - PREDICTION OF TORQUE AND PERFORMANCE FUNCTIONAL

Consider the cross sectional view of the motor as shown in Fig. 3. The stator field windings are distributed in slots which are filled with high permeable iron powder. The powder is itself backed by yet higher permeable solid iron. Three phase current passing through the stator field windings generates a traveling magnetic field in the peripheral direction. The effect of this three phase stator winding can be represented as a surface current with a cosinusoidal dependence on space and time (specifically, $\omega t - kx$). Three groups of eight slots constitute the stator used; each group being commonly excited by single phase. The winding scheme is such that adjacent slots are made to change polarity, thus giving rise to a field wavelength equal to twice the slot spacing. The fact that the three phase groups are slightly offset one from another by 120 electrical degrees provides us with the constant torque and power input characteristic of three phase devices. In this sense, therefore, the winding on the stator can be thought to be identical to a conventional three phase winding having a pole pitch equal to twice the tooth spacings.

The rotor magnets are arranged north-south/north-south, having the same spacing as the stator wavelength. For rotor/stator separation distances (in the y-direction) equal to one wavelength, the rotor field is quite dominantly sinusoidal in nature. This has been confirmed by experimental measurements of the field above the rotor surface as the rotor is spinning. We choose to represent the field at the rotor outer radius as a sinusoidal magnetization. The rotor magnets are, in turn, backed by high permeable magnetic iron.

The stator windings shown in Fig. 3 reside in slots and occupy a space "g_w" meters thick. The interstitial space is filled with iron, but not the region behind the winding in the present model. Thus, the effective permeability of the composite stator region is quite low (relative $\mu \approx 2$). We use a three phase winding discussed above with "N" turns/length each sinusoidally distributed.

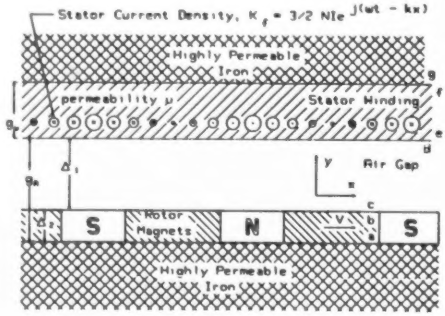

Fig. 3 Cross Sectional Model of the Linear Synchronous Motor Used in the Analysis

Theoretical predictions of torque, voltage, and efficiency [7] show close agreement to experimental measurements.

CONVERTER DESIGN

The traditional selection of the DC motor as the electrical machine defines the conversion function as fixed potential DC to a lower variable potential DC. This function is performed by a DC-to-DC converter (or chopper). By selecting an AC synchronous machine, the conversion function is then fixed potential DC to variable potential and variable frequency AC. Therefore, the power converter required is the inverter.

Synthesis of sinusoidal power waveforms with commutated thyristor inverters has been utilized for a number of years to reduce the harmonic content found in commutator-type switching (voltage-source inverter with sinusoidal pulse width modulation [8]). The recent introduction of low cost, high speed, high current MOSFETs permit switching at a frequency well beyond the audible range, further reducing the harmonic content (pulse width modulation (PWM) transistor inverter operating at a high switching frequency [9]).

A three phase MOSFET inverter is capable of producing the sinusoidal current waveforms. Two alternatives for sine-wave synthesis, currently under investigation for the powered wheelchair motor, are pulse width modulation and on-off control with hysteresis [9]. Both of these switching methods rely on the load inductance to prevent intermittent current flow. The motor inductance filters the high frequency voltage fluctuations to effect a "smooth" low frequency current waveform. This fundamental concept is illustrated in Fig. 4. When the MOSFETs are in the ON state, the full DC source potential is applied to the motor coil and current increases. When the MOSFETs are in the OFF state, the motor inductance attempts to maintain continuous current. The free-wheeling diodes provide a current path back to the DC source, so that stored inductive energy is transferred to the battery. During this period, the coil voltage is clamped to the negative of the DC source, and current decreases.

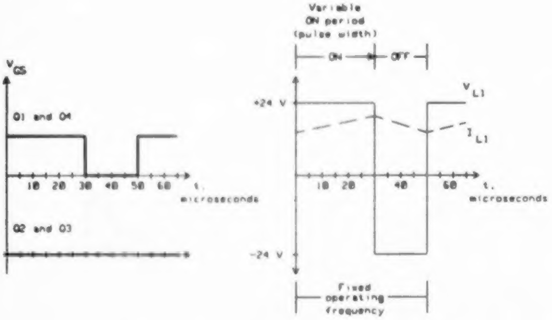

Fig. 4 Smooth Low Frequency Current Waveform Using MOSFET Inverter

The pulse width modulation (PWM) technique for sine-wave synthesis is illustrated in Fig. 5. For visual clarity, the switching frequency shown is much slower than actually implemented (currently 20 KHz with a pulse width resolution of 50). Microprocessor control provides a straightforward approach for generating the PWM sine-wave. The pulse width, which can be multiplied by a gain factor for amplitude control, is periodically updated from a look-up table containing the sinusoidal values. Frequency control is obtained by adjusting the update period.

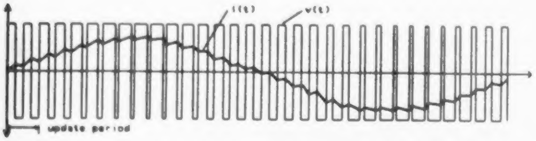

Fig. 5 Pulse Width Modulation Technique for Sine-Wave Synthesis

CONCLUSIONS

A concept for a curvilinear synchronous motor has been constructed and tested. The theoretical predictions agree well with measured performance. Based on these predictions, it is estimated that use of rare-earth magnets, we should realize efficiencies in excess of 90%. A controller has been built employing pulse-width modulation techniques which insures maximum torque generation/ampere excitation and insures synchronous operation. Attention is now being given to the incorporation of such a motor into a wheelchair.

ACKNOWLEDGEMENTS

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A COMPARISON OF THREE-WHEELED HUMAN POWERED BICYCLES FOR PERSONS WITH PHYSICAL DISABILITIES

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ABSTRACT

Four human powered trikes-the Rowcycle, Unicycle, modified Landspeeder and the Trilobike-were compared in this study. The Rowcycle and the Unicycle are commercially available; whereas the modified Landspeeder and the Trilobike are prototypes developed at the Center for Rehabilitation Technology. The study compares specifications of each trike as well as objective tests and subjective observations.

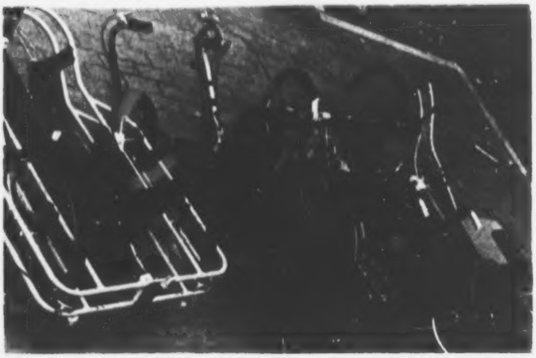
INTRODUCTION

The purpose of this comparative study is to provide consumer information about four different types of three-wheeled bicycles, it is not intended to prove one trike superior over another. Each trike has a unique wheel layout, steering and drive system. This report is meant to serve as a guide to help people choose the vehicle that best meets their needs.

BACKGROUND

The Rowcycle is a three wheeled bicycle propelled with a rowing motion. A chain and sprocket mechanism transforms the rowing motion into rear wheel rotation. Steering of the Rowcycle is accomplished via the single front wheel by tilting the seat. Individuals of varied sizes can be accommodated by its adjustability.

The Unicycle attaches to a conventional wheelchair and is hand propelled. A single wheel is used for propulsion and steering. It has a three speed hub with integral coaster brakes. The Unicycle comes in two junior sizes and four regular sizes.



Tested trikes from left to right: Rowcycle, Landspeeder, Unicycle and Trilobike.

The Trilobike is a conversion of a standard adult tricycle, specifically designed for a hemiplegic client by staff at the Center for Rehabilitation Technology at the University of Wisconsin-Stout. Modifications included lengthening the frame to lower the center of gravity and incorporating the steering wheel to allow for one handed steering.

Landspeeder components and prototype design ideas were incorporated into a modified Landspeeder at the Center for Rehabilitation Technology. This trike utilizes two front wheels for steering and a rear wheel for propulsion. The rider sits in a recumbent position and steers and brakes with hand levers. The original Landspeeder was developed by Landspeeder Inc. and is no longer in production.

METHODS AND RESULTS

The evaluation of the four trikes was divided into three facets: specifications (Table 1), objective tests (Table 2) and subjective observations and comments (included in Discussion).

Objective tests

The objective tests were standardized to the fullest extent possible. Each trike was tested in the same manner and at the same time as the other trikes. Instructions were given concurrently to all riders; each rider was rotated on the trike. Each test was run at least three times to observe patterns in the data. Under different conditions and with different riders results may differ, but data patterns should remain consistent.

Table 1 Specifications

Factors	Rowcycle	Landspeeder	Unicycle	Trilobike
Wheel Base	53 3/4	55"	45"	65 1/2"
Height wi Rider	50"	34"	49"	52 1/2"
Height	34 1/2"	33"	43"	33 1/2"
Width	36"	39"	25 1/2"	31 1/2"
Length	78"	92"	66 1/2"	88 1/2"
Weight	67 lbs	67 lbs	34 lbs*	73 lbs
Min Ground Clear	2"	2 3/4"	1 1/2"	3 1/2"
Frame Material	Aluminum	Steel	Steel	Steel
Wheel Size:				
Front	16 x 1.75	16 x 1.75	20 x 1.75	24 x 1.375
Rear	26 x 1.40	27 x 1.25	n/a	24 x 1.75
Type of Steering	Swivel Seat	Dual Lever	Std Steer crank used as handle bars	Std Steer connected to steering wheel
Type of Seating	Upright Low back	Recumbent	Wheelchair	Slightly recumbent
Speeds	3	10	3	1
Propulsion	Rowing	Std Pedal	Hand Crank	Standard
Components:				
Crank	n/a	Shimano	3pc cotter	Wald 1 pc Steel
Pedals	n/a	Shimano	Hand Pegs	Wald
Derailleurs	n/a	Sun Tour	3 speed	
Brakes	DIA Comp Al	Steel Side Pull	Internal Coaster	Internal Coaster
Tires:				
Front	Cheng-shin	Carlisle Aggressor	Cheng-shin	Dae Yung
Rear	Nimbus	Carlisle Gum-Wall		
Hubs:				
Front	Wald	Tuff Wheel	Shimano	Wald
Rear	Normandy	Shimano		Komet Super

*Unicycle without wheelchair

Braking distance. The braking test was split into two components: braking on dry and wet conditions. Because braking is exponential to speed, a speed of 12 mph was used as the base rate for each trike to most clearly demonstrate braking abilities. Riders were asked to maintain a speed of 12 mph, then brake hard as their trike crossed the finish line. The braking distance was measured from the line to the front edge of the trike.

Each bike was tested three times on a dry black top surface. The pavement, bike tires and rims were wet down thoroughly and tests were run three more times. Note that the Unicycle was not included in the wet pavement test because its performance at 12 mph on dry pavement was considered unsafe; therefore testing wet conditions at that speed would be too risky.

Table 2 shows the average braking conditions under dry and wet conditions. Under dry conditions the trikes were very similar in braking distance. The Unicycle required the most distance with 23.5 feet, followed by the Landspeeder with 22.6 feet, the Rowcycle with 17.7 feet and Trilobike with 17.3 feet. Results of the wet braking test were more varied. The Rowcycle (which had a low dry braking score) had the longest wet braking measurement, 42.5 feet. The Landspeeder needed 35.0 feet. Trilobike used 23.3 feet on wet pavement which was 5 feet more than it need on dry pavement.

Turning radius. The turning radius was determined by measuring the minimum space required to make a 180 degree turn; this measurement was divided in half to calculate turning radius. The outermost points of the trikes were marked as the rider crossed a line drawn on the floor. The riders were instructed to turn and pedal at the same time, trying to make as sharp a turn as possible. The measurements were taken from a standing point to standing point. Three trials, using alternate riders for each trial, produced results on Table 2.

The results of the turning radius show a large variation among the trikes. The Landspeeder needed the most space (111.5 inches) with variation between trials of four inches. The Rowcycle needed 107.5 inches for turning with variation of one and 1/2 inches. The Trilobike needed 58 inches varying 3 inches between trials. The minimum turning radius for the Unicycle was 46 inches, however there was a large variation (12 inches) between trials and riders.

Stability. Stability was assessed by taking each bike on a predetermined course which involved 90 and 45 degree turns on sidewalks, gravel and blacktop surfaces. The trikes began the course at a slow speed (under 5 mph) and increased to 10 mph. Four riders alternated on each bike for trials and assessed stability based on cornering ability to self-right and amount of drive attention to steering needed. The scale used 5 as excellent, 0 poor; ratings were then averaged.

Table 2: Objective Measures

	Rowcycle	Landspeeder	Unicycle	Trilobike
Average Braking Distance at 12 mph:				
Dry Conditions (ft)	17.7	22.6	23.5	17.3
Wet Conditions (ft)	42.5	35.0	-	23.3
Minimum Turning Radius (in)	107.5	111.5	46	58
Average Stability Score *	3.4	3.9	1.25	3.6
Weight Distribution:				
Front %	13	65	17	25
Rear %	87	35	83	75
Distance/Revolution: **				
Minimum (in)	94	127	70	128
Maximum (in)	193	315	126	

*based on a Likert scale: 5 = excellent, self rights, steers no handed to 0 = poor cornering, needs constant attention, dangerous steering problems, uncontrollable.

**Linear distance traveled per crank revolution or row stroke (gear ratio x wheel diameter x pi)

The Landspeeder received the highest ratings for stability with an average score of 3.88. At high speeds was less stable. The Trilobike received a rating of 3.63. Riders questioned its ability to corner at high speeds. The Rowcycle rated third with a score of 3.38. Major concerns included ability to row at a high speed while coordinating body position to negotiate corners. The Unicycle was rated poorest of the four trikes in stability with an average score of 1.25. The steering mechanism is also the propulsion (the hand crank). When a rider is riding in a "straight" line, the front wheel makes an "S" pattern, turning with the hand that is pumping on the crank. A turn, therefore, is difficult because the rider needs to pump one hand more than the other.

Stability for all of the trikes was a major concern at high speeds. The Unicycle in particular, was very unstable at speeds above 7 mph.

Weight distribution. Weight distribution was measured by weighing each trike at the front and rear wheels with a 160 pound person sitting in riding position. Weight distribution plays an important role in traction, braking performance and steering stability. A vehicle needs enough weight on its drive wheel(s) for traction, but also sufficient weight on the wheel(s) used for steering. The Rowcycle was measured with its seat in the far rear position which resulted in 13% of its weight on the front wheel and 87% on the rear wheels. More weight could be put on the front wheel by moving the seat forward. The Unicycle has similar weight distribution (17% front, 83% rear), but results in a loss of traction since weight is lightest on the wheel that controls drive and steering. The Trilobike has a larger percentage of weight in the front (25% front, 75% rear) than either the Rowcycle or the Unicycle, but still experiences handling problems due to a "light" front end. The Landspeeder, with 65% of its weight on the front wheels, handles well, but experiences traction problems on loose pavement.

DISCUSSION

Rowcycle

The Rowcycle can be used by persons with good upper body strength and trunk stability. It is suited for short to medium distance riding (1-10 miles) on fairly flat terrain. The rowing action requires rider to use many muscle groups. Becaus the rider is low to the ground, the Rowcycle is fairly stable. Riders should be cautious of street travel due to its low visibility to traffic. Riders should also be cautious corneri at high speeds. Some design factors to consider include its limited gear range, steering that requires trunk control and a drive mechanism that depends on elastic cords.

Recommendations. Because the rider's trunk contacts the wheels during turning, an enclosure or fender is needed. The seat base, which is constructed of 1/2 inch plywood, cracked during testing. This should be replaced with more durable material. Also, an anti-tilt feature for the seat would aid in transferring in and out of the Rowcycle. A limit on rear oar travel would prevent the rider's hands from contacting tires at the end of a stroke.

Unicycle

Wheelchair users with good trunk stability and upper body strength can use the Unicycle. It works well for short distance trips at slow speeds. The Unicycle is portable, light weight, relatively inexpensive; replacement parts are readily available for its three speed hub. Because steering and propulsion are done with the same wheel, it is hard to maintain a straight course when riding. The short wheel base and high center of gravity make it unstable at speeds above 7 mph. It loses traction due to a small amount of overall mass on the front wheel.

Recommendations. Four clamp bolts on the goose-neck come stock with flat washers. These should be replaced with lock washers. Since attaching the Unicycle to a wheelchair is performed at an awkward angle, some users may require modification of the attachment lever. Modifications of the Unicycle are necessary to fit lightweight chairs.

Landspeeder

Users of Landspeeder need to have good leg strength and coordination. Because of its recumbent seating it can be used by persons with limited trunk stability and/or lack of balance. It works well for short to long distance riding (1-20 miles) on flat to slightly hilly terrain. The Landspeeder's lowered frontal area reduces air drag, but causes the problem of visibility of the rider to traffic. The Landspeeder requires low gearing to climb hills because the rider's weight can not be pushed directly on top of the pedals.

Recommendations. At the present, braking is done independently on each front wheel. Both front wheels should be combined on a single lever and a rear brake added. Fenders should be added to keep road debris being sprayed on the driver.

The Trilobike, an adult trike modified for a hemiplegic client by the students and staff at the Center for Rehabilitation Technology.

Trilobike

This trike was specifically built for persons with at least one strong arm and coordinated leg. It is suited for short to medium distance riding (1-10 miles) at low speeds. The Trilobike was made by adding a rear end kit to a standard woman's bicycle. Therefore most parts are standard bicycle components, although the rear end kit is specialized. The Trilobike is high off the ground and visible to other traffic, but because of the high center of gravity, it is not stable.

Recommendations. Wheels should be cambered in at the top to increase stability. Fenders should be installed on all wheels to protect rider from road debris.

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Westport, CT 06880

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3164 N Marks, #120
Fresno, CA 93711
209-268-1946

Unicycle
CP 276, Station N
Montreal, Quebec
Canada H2X 3M4
574-435-9128

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AN ADJUSTABLE HEIGHT MANUAL WHEELCHAIR FOR A VOCATIONAL APPLICATION

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ABSTRACT

An adjustable height wheelchair system was designed and built to enable a T-10 paraplegic to return to work as an autobody repairman. The system is based on a commercially available patient lift chair designed for transfers and bathing. An electrically operated hydraulic lift permits the seat height to be raised or lowered from 6 inches to 29 1/2 inches from the ground. The development of the system from the client evaluation through the completed system is described.

INTRODUCTION

Vocational rehabilitation assistance for disabled individuals is one of the clinical services provided by the Rehabilitation Engineering Program within the Department of Physical Medicine and Rehabilitation at the University of Michigan Medical Center. A unique case was referred to the Rehabilitation Engineering Program by the Occupational Therapy Work Evaluation Program involving a paraplegic returning to his vocation of autobody repair. A means for him to have access to various heights on a car in order to perform his job duties was the challenge presented to the rehabilitation engineers.

BACKGROUND

The client, S.K., is a 26 year old man who sustained a spinal cord injury in an automobile accident resulting in T-10 paraplegia. He is a certified autobody mechanic and had been working in a small shop for eight months prior to his injury. His work included welding, body repair, sanding, taping, painting, and buffing. S.K. had an excellent work record and a strong desire to return to his vocation. The shop manager also expressed his desire for S.K. to return to work.

METHODS

Evaluation

A work site visit was made by S.K. and an Occupational Therapy Work Evaluator. The shop was determined wheelchair accessible and S.K. was able to maneuver his manual wheelchair through the shop and doorways. The shop manager indicated that the primary working surfaces in the shop were between 12 inches to 5 feet from the floor, with the majority of the work tasks performed from a creeper at heights between 12 inches and 3 feet. S.K. stated that it was most important for him to get down to floor level.

It was apparent from further discussion with the client that a system based on the following design criteria would be optimal for his needs: an adjustable height seat, a stable base, a proper seating system, and a means for self propelling.

Figure 1

As a first step, commercially available devices were investigated. A patient lift chair by Arjo Hospital Equipment (1) designed for transfers and bathing and in use at the University Hospital was identified. This chair has a cantilevered seat with an electrically operated hydraulic lift that raises and lowers the seat. The Arjo chair seemed well suited to modification for this application. After weighing the advantages and disadvantages of a custom device versus a modified commercial device, the Arjo chair was selected as the basis for S.K.'s system.

Simulations were performed with S.K. in an Arjo lift chair to determine the feasibility of attaching rear wheelchair wheels to the structure (figure 1). S.K. practiced transfers from his standard manual wheelchair to the Arjo chair without difficulty. Various cushions were also tried with S.K. seated in the Arjo chair.

Design

The final design of S.K.'s wheelchair system included structural modifications to the chair and base of the Arjo system as well as an added leg rest structure. Two mechanical engineering students at the University of Michigan completed the mechanical drawings of the structural modifications as part of their senior design project. The switch-activated hydraulic lift mechanism did not require modification.

An outside contractor was hired to complete the structural modifications. The base of the system was narrowed to the width of S.K.'s standard manual wheelchair by cutting the crossbar and welding it back onto the base. A support structure consisting of 1 inch square steel tubing was also welded to the base. 24 inch diameter Quadra (2) wheelchair wheels were attached to the vertical bars of the support structure with Quadra center mount axle plates and axle pins. This mounting provides flexibility and adjustment in the positioning of the wheels. Wheel locks were also attached to the vertical bars of the support structure. The two front casters on the original base of the Arjo chair were left in place. As a precautionary measure, anti-tippers were put on the base of the chair.

The armrests on the Arjo chair are designed to swing back out of the way for transferring. They were cut shorter and brought in closer to the center line of the chair to accommodate S.K.'s body size.

A one-piece leg rest and foot plate structure was designed to slide forward automatically as the chair is lowered. The foot plate is hinged to the leg rest and can fold down against the leg rest. Stops ensure that the leg rest returns to its standard position when the chair is raised. A double-roller caster on the bottom of the leg rest permits maneuverability of the system if the seat is at a level where the foot rest is in contact with the ground.

The seating system is comprised of a solid seat and back with 1/2 inch medium density foam on the back. For aesthetic purposes, black naugahyde was used to cover the seat, back, and leg rest structure. A Vasio-Para cushion (3) was selected from a number of commercial cushions because it provided the most stable seating and was the most comfortable to S.K.

A layer of dense rubber was glued to the foot plate for longer wear and durability. Standard bicycle handlebar pads were put on the arm rests for comfort and grip. The chair and base of the system were sandblasted and painted black from their original blue per S.K.'s request. For safety and added stability, a seat belt was bolted to the chair frame. A fire blanket to place over S.K.'s lap and legs to protect them from sparks that may occur in the shop was also provided.

RESULTS

The completed system with S.K. lowering the chair is shown in figure 2. The lift is powered by a rechargable battery. The seat height range without a cushion is approximately 6 inches to 29 1/2 inches from the ground. When the chair is in its lowest position so that the leg rest is resting on the ground, the hinged foot plate can be lowered onto the leg rest providing a flat surface for S.K. to place his legs. He then has the option to stretch his legs out in front of him or to cross his legs in a lotus position on the leg rest. He will need to sit with his legs crossed if the nature of the job he is doing doesn't permit outstretched legs.

The 24 inch diameter wheels allow S.K. to propel the chair in all directions and at all seat height positions. However, the system is not particularly maneuverable. The wheelchair wheel axles are mounted further back from the most efficient position so that they do not interfere with S.K.'s arms when the seat is lowered to the ground. In addition, the chair is heavy (approximately 90 lbs.) and quite long (approximately 40 inches). The width of the chair (22 inches) is comparable to a standard narrow adult-sized wheelchair.

DISCUSSION

Providing a custom designed system for an individual can be costly, time consuming, and often may require numerous refinements before it is satisfactory. The system described in this paper is a custom one which required minor structural modifications of a commercially available product. The assessments done with the previously unmodified Arjo chair (figure 1) provided assurance that the final design would be feasible. Although some refinements of the system are expected, the extensive effort often associated with a custom designed system should not be necessary.

An adjustable seat height wheelchair was previously provided in our laboratory for a young child with congenital malfunction of all four extremities (4). There are a number of vocational and avocational activities in which wheelchair dependent people could benefit from an adjustable height seat. Although the current system lacks good maneuverability, the ability to move the height of the seat should greatly enhance S.K.'s work productivity.

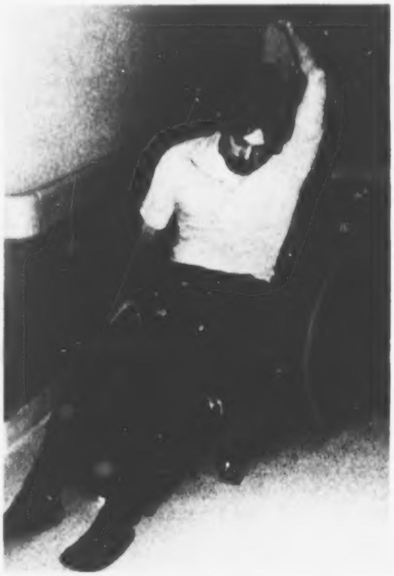

Figure 2

S.K. is very pleased with the completed system. He will reenter the work force in April of 1987 at the shop he was employed prior to his injury. He will be doing both mechanical work on cars as well as some office work. It is hoped that the adjustable height manual wheelchair will contribute to S.K.'s performance and success on the job.

ACKNOWLEDGMENTS

Funding for this project was provided by Michigan Rehabilitation Services.

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ADDRESS

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MOBILITY SYSTEMS FOR PEOPLE OF SHORT STATURE
TWO CASE STUDIES

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ABSTRACT

This paper examines the needs for mobility of two individuals of short stature. Both of them use their legs to assist in propelling their present wheelchair systems. Both have orthopedic problems which have been aggravated by their present system. First, the two case studies will be presented. Then, factors to be considered in the prescription of mobility systems for people of short stature will be discussed.

INTRODUCTION

People of short stature often have accompanying physical disabilities which necessitate the use of a wheelchair or other mobility device. For children, this is not as much of a problem as for adults, as there are small-scale systems available. Even with them, however, there are problems similar to those encountered by adults with respect to reach and seat depth, as proportions assumed are for the "average" child or adult. Standard mobility systems do not fit little people, as it is often their "not-so-average" trunk and limb proportions that make the difference between whether they can reach the handrims or controls and whether or not the chair and its accessories fit their bodies.

The following two case studies show two very different people with the same basic need: a mobility system for a size small person in a size large world (Fig. 1).

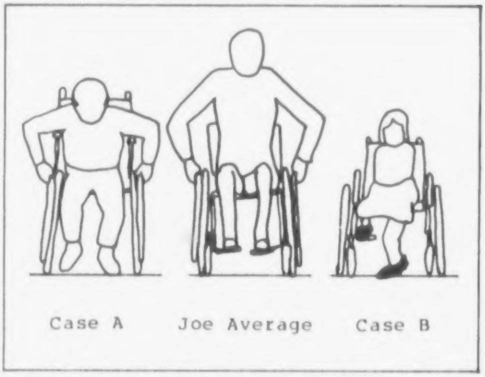

Figure 1. Comparison of Short Statured Users with Average User

CASE STUDIES

Case A

N.B. is a 40 year old man who measures in at either 4'6" or 4'2", depending on which leg you're measuring from. N.B. uses a standard adult-sized wheelchair with the big wheels up front and two rear casters. He sits on the front edge of his sling seat, using both his legs and the handrims to propel his wheelchair. He has Osteogenesis Imperfecta. Because of this, his limbs are bowed, he has poor balance, mild scoliosis, and a pelvic obliquity. He can walk very short distances, but prefers not to due to his fear of fracturing a bone should he lose his balance. He works fulltime and lives alone, transfering his wheelchair into his car independently.

Present system. His present system is oversized for him. He cannot sit back in the chair, or the popliteal region is compressed,and his feet and legs become uncomfortable. When he is at the top of his stroke on the handrims, his shoulders are abducted to about 70 and his elbows are flexed to around 90 . This puts alot of stress on his elbow joints and, as a result, he is experiencing enough pain to warrant surgery. This is probably exacerbated by having to lift a 45 pound wheelchair into his car. He also has alot of pain in his hip, possibly aggravated by sitting on sling upholstery with a pelvic obliquity. The armrests are about 2" below his armpits, and the footrests were in their lowest position, acting as spoke guards. Even at their highest adjustment, they did not come not close to reaching his feet.

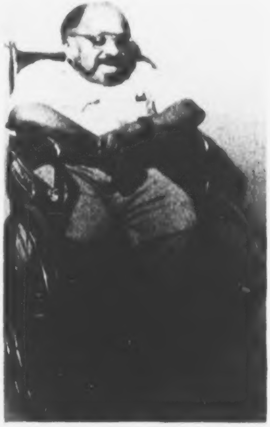

Figure 2. N.B.'s Present System

System design. After an unsuccessfull search for a commercially-available option (there were no lightweight wheelchairs with the casters in the rear), the following design was developed:
A two-component system consisting of a lightweight, foldable base upon which you place a seating unit. The two-part design is advantageous because it reduces the amount of weight he has to transfer into his car at any one time. He removes the seating component, puts it in his car,and then he folds the frame and puts it in. The entire system weighs 28 pounds. The heaviest part, the frame and wheels, weighs about 18 pounds. This cuts the load he is required to lift at one time considerably. Measurements were taken as to seat depth, armrest height, footrest placement, seat height, back height, seat width, etc. The two parts will be discussed below.

Seating Component:
Because his preferred sitting height differs from the ideal height from which to propel his wheelchair, a bi-level seat was designed. The front half of the regular seat folds back to expose a lower level platform upon which he sits when moving (Fig. 2). In its folded position, the regular cushion serves as a backrest. The seat and backrest fit his body. There are swingaway armrests.

Bi-level Seat

Figure 3.

Base Component:
The base is made of chrome-molly tubing and folds easily. The big wheels are up front ,and there is a single rear caster. In the design stage, it was found that a single caster made for a more maneuverable chair without compromising stablility. The handrims of choice are larger in diameter than usual and have a friction grip. The big wheels are 20" in diameter and make propulsion much less stressfull for his elbows. Pneumatic tires were chosen for a smoother ride. The footrests are height-adjustable and fold up into the frame.

Overall, it is hoped this design will prove to be much less stressfull, even beneficial. The mode of propulsion, that of using his legs as well as handrims was maintained because of the positive effects on his bone density and his cardiovascular system. A vertical position benefits his respiratory and digestive systems as well [1].

Case B
N.G.is in her early forties. She is of short stature, and was born without arms and phocomelia of her right leg. As she sits in her present system, her right foot is 6" from the seat,and her left foot is 15" from the seat. N.G. has scoliosis, hyperlordosis in her lumbar area, and a pelvic obliquity. The primary orthopedic concern, however, is the condition of her left knee. It stands to reason that this joint, having taken the place of all four throughout her life, would be showing signs of wear. The ligaments are stretched to the point where her knee is easily subluxed. Ligamentous laxity is common among a number of categories of people of short stature [2].
Present system. In N.G.'s present mobility system, she has a wheelchair which was scaled down by her father. It has sling upholstery, armrests which offer the lateral stability she needs for her trunk, and a makeshift footrest for her right foot. To propel her chair, she slides forward in the seat, and uses her left leg. In addition to everything else she does with her left leg, this puts a great deal of stress of her knee. It is not the forward motion so much as the motion and energy required to steer the chair that results in the strain on her ligaments.
In looking at her needs for mobility, the question of providing a powered vs. manual system is a tough one. There is a definite need for a powered chair, preferably one with height-adjustability. This would allow access to countertops at home, tables, the contents of the refrigerator, etc.. Up until a couple of years ago, she was working as a vocational rehabilitation counselor. She is experiencing too much discomfort at this point to consider working. She likes to get out in the community, and for this reason she requires a manual chair as well. This would allow her to go places with friends in their cars. Hence, the recommendations for her include plans for both a manual and an electric mobility system.
Proposed solution. The proposed manual system would still be propelled with her left leg. However, the steering would be controlled by a mechanism operating a single caster in front. She would operate the mechanism with her right foot. This would greatly reduce the stress to her

knee. There would be a custom-contoured back which would provide lateral supports for stablility. The system must be lightweight and easily transported in a car. It must also come with handles at a convenient height for people to assist her.

The powered systems available on the market which come close to her size and offer height-adjustability are the Turbo and the Permobile. The controls would be mounted for operation by her right foot. Other systems have been custom-built but there is not much of a choice on the market [3]. A request for approval for funding has been submitted.

DISCUSSION

The two people in the case studies have very different needs and abilities. That is typical of what you'll find in working with people of short stature. The different types of short stature will produce very different clinical manifestations [2].

Factors to be taken into consideration when working with a person of short stature, or "little people", include the following:

-the environments the person finds themselves in on a day-to-day basis
-their physical abilities and limitations
-the position they need to be in to enable them to propel or control their device
-the means by which they can propel themselves
-longterm physical effects of the chosen method of propulsion
-the orthopedic difficulties faced by them
-the sitting height they would prefer (at times, a person will need more than one sitting height)
-there are psychosocial reasons behind the seat height preference of some people; a common attitude encountered by some little people is that because of their size, they are treated as children. One woman I spoke to chooses to use a Pony for this very reason. It puts her at eye level with her peers, and she feels she is taken more seriously as a result.
-physical benefits or detriments of propelling it manually

Seating in general is a problem for little people. Many times, if they sit with their back resting on the back of a chair, their feet will be left hanging, causing the popliteal region to compress and their feet and legs will go numb. It also encourages a kyphotic sitting posture. Proper postural support is critical not only for comfort, but to discourage a tendency towards physical deformities progressing. Many individuals of short stature have orthopedic complications. These may range from spinal stenosis to scoliosis to severe ligamentous laxity of various joints. One should be aware of which of these conditions your client may have or may be prone to. Other alternatives for propulsion should be explored. Two examples of devices used which would facilitate manual propulsion without reaching down to the wheels include the lever-drive concept [4] and the drive mechanism employed in the vertical wheelchair [5]. Sometimes, it would be most beneficial for a person to go with a powered form of mobility to save their joints. Many people of short stature tend to go for the three-wheeled Amigo or Pony. It is a much more expedient means of travel than by foot or by pushing a manual wheelchair.

ACKNOWLEDGEMENTS

This work was undertaken as part of the clinical training program at UVA-REC. There are several individuals I would like to thank for their contributions. First of all, I would like to thank Bob Bryant, the technician at UVA-REC who built the prototype for N.B., and Colin McLaurin for his seasoned advice. Many thanks for support in the way of parts and N.B.'s final product fabrication from Stainless. Thanks to the staff at International Center for Skeletal Dysplasia in Towson, Maryland and all the "little people" I talked to for their invaluable information.

Finally, thanks to N.B. and N.G. for their patience and trust.

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A VARIABLE POSITION, COMPACT FOLDING WHEELCHAIR

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ABSTRACT

A wheelchair (WC) with some unique features was designed and developed to a second prototype stage. The principal design considerations included capability for adjustment of the seat position along the longitudinal axis while seated in the WC, and compact folding. Both of these objectives were accomplished in the current prototype. A further iteration of the design is under development. The third prototype should retain all the advantages and compactness of the present version with the advantages of simpler construction, reduced weight and easier folding.

INTRODUCTION

There are several factors that limit the mobility and performance of wheelchair (WC) users. These factors can be grouped into two major catagories: the individual characteristics and capacities of the user and the design limitations of WCs. These various factors have been identified and in many instances, have been quantified, over the past several years. The consequences of positioning of the user along the vertical and longitudinal axes of the WC with respect to propulsion efficiency, maneuvering, rolling resistance and stability have been rigorously discussed (1). When a user is WC dependent for mobility these factors are of considerable importance, particularly so for active users, and should be considered in the prescription and selection of the WC.

DESIGN CRITERIA

It was the authors' intent to design a WC for active users which would allow for easy adjustment of the seat position along the longitudinal axis while seated in the WC. A second objective was to design the WC so that it could be folded compactly for stowage in compact cars or, perhaps in overhead compartments on airliners (with drive wheels removed). Other design considerations included: minimizing weight, provision of a solid seat, robust construction, simplicity and safety.

DESCRIPTION

The WC is of tubular chromoly steel construction. The fore-aft adjustment of the seat with respect to a fixed chassis was accomplished with a 4-bar mechanism consisting of vertical members articulated about cross members linking the side rails of the sub frame (chassis). The rear, lower cross member also serves as a through axle for the main wheels. The disassembled parts are shown in approximate relationship to one another in Fig. 1-a. A partial assembly of the right side of the frame with the corresponding parts for the left side shown in an exploded relationship is presented in Fig. 1-b. Complete frame assembly with only the seat and seat back removed is shown in Fig. 1-c. The fully assembled WC is shown in Fig. 1-d. It can be seen that the 4-bar parallelogram structure which includes the chassis side members and front and rear vertical members is completed by the plywood seat which also serves as a structural component. Positioning of the seat is accomplished by allowing the legrest assembly which is articulated from the front vertical support member to slide within a short tube which is mounted in a sleeve attached to the chassis side member via the caster assembly. This mechanism is evident in Fig. 1-b to 1-d. The locking mechanism is based on friction induced with a plunger inside the rotating section of the slide housing tube. This plunger is actuated by a cam on the end of the tube which is positioned parallel and lateral to the legrest assembly. The fore-aft movement of the seat with respect to the chassis is accomplished by pushing or pulling on these tubes while the plunger is disengaged. Locking is then accomplished by rotating these tubes to force the plungers against the legrest members. The caster assembly consists of two plates and a tubular housing for the slide tube (described above). This assembly articulates about the front lower cross member and is locked in position along the chassis side rail by a retractable, spring-loaded pin. The caster housing is attached to the assembly by a bolt at its lower end about which it is able to rotate for folding. This housing is fixed in place by a flange that inserts into a channel on the upper surface of the housing when the assembly is deployed for operation of the WC.

Weight Distribution by Components

The total weight of the WC frame and casters was 11.24 Kg. (24.8 lbs.). The main wheels were 4.63 Kg. (10.2 lbs.). The distribution of weight for the various components of the WC is as follows:

Side tubes (2)	1.12 Kg.
Vert.support (rear)	.6
Vert.support (front)	.4
Leg rest assembly	1.31
Caster ass'y & housing	1.78
Casters and forks	1.54
Locking and adj.tubes	.32
Seat	1.3
Backrest assembly	.73
Misc.fittings, etc.	1.66

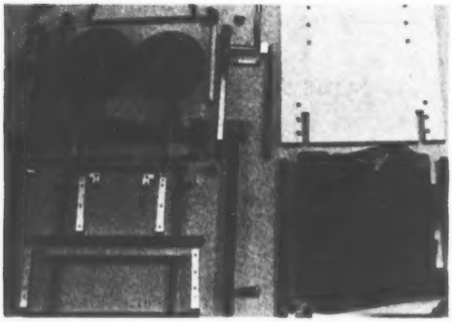

Fig. 1-a.

Fig. 1-b.

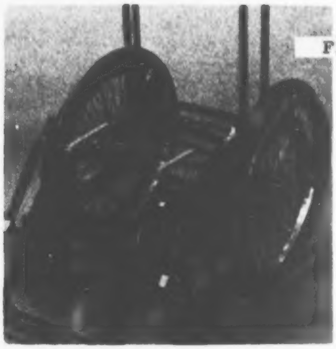

Fig. 1-c.

Fig. 1-d.

Position Adjustment

As noted above, the seat position of the WC can be adjusted along the longitudinal axis with respect to the chassis by the operator while seated in the WC. This adjustment extends over a range of four inches with the backrest directly above the axle in the most forward seat position. The seat may be moved aft 4 inches from this position. The adjustment is effected by pushing (or pulling) on the adjustment tubes and then locking the seat in place. This requires only a small amount of force which can be reduced by inclining the trunk in the direction of the adjustment. The extreme positions of adjustment are shown in Fig. 2-a and 2-b.

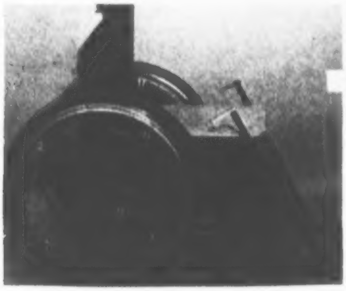

Fig. 2-a.

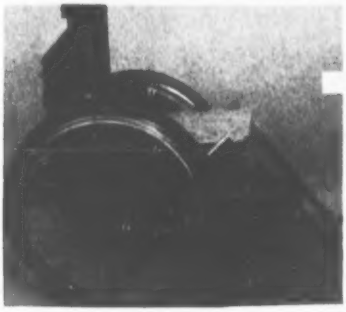

Fig. 2-b.

Folding

The manner in which the WC is folded is illustrated in Fig. 3-a to 3-d. The quick release main wheels must be removed prior to folding. Folding is initiated by retracting the locking pins for the caster assembly which are held open by detents and releasing the friction locks. It can be seen in Fig. 3-a that the caster assembly rotates about the forward horizontal member with simultaneous forward rotation of the vertical supports and sliding of the legrest assembly. This action is completed in Fig. 3-b. The casters are next rotated inward to rest on the seat surface (3-c). The folded WC with the backrest folded forward is shown in Fig. 3-d. The folded dimensions are 22.5" (width) x 26.25" (length) x 5". The overall width is in excess of the seat width of 17.5" due to the offset of the adjustment tubes.

Fig. 3-a.

Fig. 3-b.

Fig. 3-c.

Fig. 3-d.

Anti-tip Mechanism

An anti-tipping mechanism with 2" trail wheels mounted on an adjustable two-segment boom has been designed but not yet mounted on the WC. This mechanism adjusts with the change of position so that the wheel will contact the ground just after the WC passes the balance point about its pitch axis. This mechanism can be manually deployed and locked with the trail wheels in contact with the ground when the WC is in its normal attitude. This allows for the main wheels to be removed with the operator still seated in the WC. In this mode the WC is shorter and narrower and can be used for negotiating confined areas such as bathrooms and airline aisles.

DISCUSSION

It is the authors' opinion that the design objectives have been accomplished to a reasonable degree. Although there has been no opportunity to obtain user responses, the preliminary evaluation of the WC has been most encouraging. The significance of the adjustment feature of the WC by a seated operator may not be immediately obvious. It may be appropriate, therefore, to point out that activities such as transfers, wheelies, climbing or descending grades, traversing side-slopes, etc. are enhanced by optimizing seat position and mass distribution about the pitch axis of the WC. It has also been confirmed that such factors as propulsion efficiency and rolling resistance can be improved by optimal seat positioning and mass distribution. It is also worth noting that the adjustment capability would be useful in positioning the WC in proximity to desks, tables and other appliances and furniture encountered in a living environment.

It is evident that the WC folds to as compact dimensions as would appear possible without disassembly. This would enable the use of very compact vehicles (e.g., sports cars and other 2 seat vehicles). The necessity for the removal of the main wheels may be regarded by some as a disadvantage; however, it should be recognized that this reduces the weight by more than 10 lbs. and allows for stowage in small compartments and in 3 parts. The operator can still be mobile with the wheels removed by using the trail wheels and propelling the WC by pulling (pushing) on fixed structures (door frames, car door handles, etc.).

A third prototype is under development which should result in a weight reduction of 5 to 8 lbs. and greater simplicity of folding.

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CUSTOMIZED WHEELCHAIR FOR A CEREBRAL-PALSIED ADOLESCENT

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ABSTRACT

The author has customized an Invacare Rolls IV electric wheelchair to enhance the utility, safety and enjoyment of the chair by his 14-year old, non-verbal, cerebral-palsied son. A speech synthesizer is installed in the chair. Access to the synthesizer is via an Apple IIc computer, also installed in the chair. Other additions include head-stick operated chair controls, complete lighting system with flashing beacon, horn, siren/buzzer, chime, annunciator, quick-release lap tray, arm and hand restraints, staff holders, decorator panels, and storage compartments. The computer system, lighting and other electrical accessories are all powered from the chair's 24-Volt electrical system. This equipment is described in detail, including electrical power consumption data and a description of the application and success of each item.

INTRODUCTION

An Invacare Rolls IV wheelchair was purchased in January, 1983 for the author's son, Alfie, who has severe cerebral palsy. Alfie's voluntary control movements are limited to the head, hence all keyboard and control functions are via use of his headstick. A number of improvements have been made to the original chair which allow him to drive the chair, to speak by using a speech synthesizer/computer and run Apple II computer programs on an installed Apple II computer. Additional features were added to enhance the safety, utilization and enjoyment of the chair and are accessed through a second headstick-controlled keyboard.

WHEELCHAIR ENHANCEMENTS

Mobility

Since Alfie lacks hand control to operate the chair using the conventional side-mounted, ball-handled joystick, an alternative was necessary. To provide a connection between the headstick and joystick, Alfie's occupational therapist substituted half of a tennis ball for the solid, spherical ball that came with the original equipment. The chair's controller was then attached to the lap tray at a distance within easy access of the tip of the headstick. This configuration was immediately successful, with Alfie successfully driving the chair through a wheelchair obstacle course one or two days after his first drive.

As shown in the figure on the following page, a plastic funnel with three-inch mouth was later substituted for the tennis ball. A metal rim was added at the top of the funnel to help prevent the eraser-tipped headstick from slipping out of the funnel; it also provided an improved headstick-contact surface for moving the joystick when backing the chair.

To provide space for the computer keyboard, a vertical-sided, two-inch diameter metal funnel was recently substituted for the plastic one, and the controller moved three inches to the left of center. These changes have had little noticeable effect on Alfie's ability to control the chair.

Incorporation of the high/low and indoor/outdoor controls into the control keyboard has given Alfie additional freedom of mobility. Previously these controls were only operable by the attendant, requiring too much pressure to be operable with the headstick.

Lighting System

The lighting system consists of two type 4411, 35-Watt sealed-beam headlamps mounted in flexible-rubber boots, togethe with colored side and tail lights, six lamps total. Alfie now operates the chair under dark outside conditions with confidence. The lights help assure the safety of the wheelchair, even when operating on dark streets, roads or parking lots. Additional safety and enjoyment are provided by a yellow flashing beacon which is used on occasion.

An addional pair of low-Wattage lamps is provided for illuminating the undercarriage around the tie-down bolt. These lamps are used at night when attaching and detaching the chair to the tie-down pin on the floor of the lift-equipt van used to transport the chair.

Other electrical/electronic accessories

The horn (original equipment), chime and siren are useful for their safety and entertainment value. For a non-vocal teenager, these accessories provide an important means of getting everyone's attention either for showing off or for calling attention to the fact that others need to get out of the way.

The AM/FM radio provides a means of entertainment which Alfie can turn on or off at will from the control keyboard. While he cannot tune the present unit, total control should be possible by substituting an electronically-tuneable car radio.

The annunciator is provided for notifying teachers and parents that messages have been written in Alfie's notebook. This notebook is stowed in an area immediately behind the seat. Previously, it was possible to inadvertently neglect to check the book for important new messages on arrival at school or at home. Using the annunciator, a flashing red light is displayed when there is a message. A buzzer sounds about every thirty minutes until the light is turned off.

Twelve-Volt accessory outlets are provided for low-current (limit two Amperes total) accessories. These outlets have been used to power Christmas tree lights used to decorate the chair for school and church programs, as well as to power the flashing beacon and other accessories.

Mechanical Enhancements

The Summit Seating System provides custom-molded polyurethene seat and back cushions for maximum support and comfort.

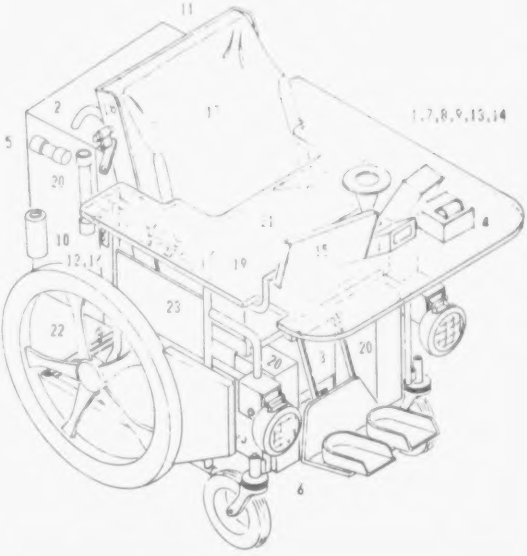
Arm restraints are used most of the time to prevent uncontrolled arm and hand interference with the joystick, keyboards and off-chair objects. Hand restraints are generally used as well when driving the chair to prevent contact with nearby objects.

The half-inch thick, polycarbonate table is attached to the original chair's horizontal tubing sections on the sides of the seat, using spring-loaded pins. The table is removed simply by pulling out on the pins and moving the table forward. To reinstall the table, it is easily pushed rearwards and down until the pins drop into place. The chair controller and keyboards are mounted on a common arm which is swung out of the way before removing the table.

CUSTOMIZED WHEELCHAIR FEATURES

FEATURE	PART NO.	CLASSIFICATION	SWITCHED BY OPERATOR	ATTENDANT OVERRIDE	ATTENDANT ONLY	VOLTAGE VOLTS	CURRENT AMPERES
ELECTRICAL/ELECTRONIC							
JOY STICK CONTROL	1	MOBILITY	X	X		24	
CHAIR POWER SWITCH	1	MOBILITY	X	X		24	
CHAIR POWER HI/LO	1	MOBILITY	X	X		24	
CHAIR INDOOR/OUTDOOR	1	MOBILITY	X	X		24	
APPLE IIC COMPUTER	2	COMPUTER/COMMUNICATION			X	12	1.4,.64*
VOTRAX SPEECH SYNTH.	3	COMMUNICATION			X	12,15	U
IMP PRINTER	4	COMMUNICATION			X	12	.1,.7**
MAIN LIGHTING SYSTEM(6)	5	UTILITY/SAFETY	X	X		24	2.8
TIE-DOWN LIGHTS(2)	6	UTILITY			X	24	.26
HORN	7	SAFETY	X			24	U
CHIME	8	SAFETY/ ENTERTAINMENT	X			12	.025
SIREN	9	SAFETY/ ENTERTAINMENT	X			3	.15MAX
ANNUNCIATOR	10	UTILITY			X	12	.055
AM/FM RADIO	11	ENTERTAINMENT	X	X		9	.05
FLASHING BEACON	N	SAFETY/ ENTERTAINMENT	X	X		12	.1
12-VOLT ACCESSORY OUTLETS	12	UTILITY/ ENTERTAINMENT	X	X		12	
CLOCK	13	UTILITY					
CONTROL KEYBOARD	14	UTILITY/SAFETY ENTERTAINMENT	X			12	
COMPUTER KEYBOARD	15	COMPUTER/ COMMUNICATION	X			12	.20
ELECTRICAL CONTROL PANEL	16	UTILITY			X	24	
MECHANICAL							
SUMMIT SEATING	17	UTILITY					
ARM RESTRAINTS	18	UTILITY					
HAND RESTRAINTS	19(2)	UTILITY					
STOWAGE COMPARTMENTS	20(7)	UTILITY					
QUICK RELEASE TABLE	21	UTILITY					
TOW HITCH	22	UTILITY/ ENTERTAINMENT					
DECORATOR PANELS	23(2)	ENTERTAINMENT					

N=NOT SHOWN ON DRAWING
*=1.4 AMPERES WITH DISK RUNNING, .64 AMPERES OTHERWISE
U=UNKNOWN
**=.1 AMPERES IDLE, .7 AMPERES PRINTING
TWC 29MAR 1987



An eye bolt, installed between the safety wheels at the back of the chair, provides a "trailer hitch." By swinging the battery case forward, the open handle of a wagon or other toy can be attached to the chair for towing. This provides some social interaction by allowing Alfie to pull other children (and adults) in a wagon. It also allows him to pull toy cars and other mobile toys which he could otherwise not do.

Lastly, decorator panels have been added on each side of the seat to provide variety in the appearance of the chair. These panels allow new slogans, travel posters, works of art, colored panels etc. to be installed from time to time to give the chair a variety of themes.

COMPUTER AND COMMUNICATION SYSTEMS

The Apple IIc computer was chosen because it can run the ubiquitous Apple II software, can be interfaced to the speech synthesizer and printer installed on the chair and operates from the chair's battery. Initially, the chair could only be configured for either computer or powered operation, precluding use of the computer/voice synthesizer when the chair controller was in place. This problem was alleviated by repackaging the keyboard so that it is now remote from the rest of the computer, i.e. the computer resides in one of the stowage areas at the back of the chair while the keyboard is mounted immediately to the right of the chair controller. The operator now has access to the computer, chair controller (joy stick) or control keyboard any time he desires, hence the name Full Time Access System (FTAS).

It was necessary to use optically-coupled isolators between the keyboard and computer to illiminate destruction of the computer's keyboard decoder chip by static electricity. The electrical structure of the keyboard, being powered directly from the chair's system rather than by the computer's power supply, is transparent to the computer, making it possible for keyboards other than the IIc keyboard to be substituted, providing the proper logic is used to translate the keystrokes to appropriate signals. The control, shift, caps lock and open-apple keys of the present keyboard were replaced by locking keys with indicator LEDs; they can now be used for two-key functions using one finger or, in Alfie's case, the headstick.

Computer Speech Program

Alfie has been trained at his school to used the ETRAN system; he has the numerical codes memorized for over 300 words. Communication via ETRAN is tedious and requires the "listener" to either know the codes or constantly refer to a wordcard. Additionally, communication with those who are not familiar with the system is precluded.

A solution was found by installing a Votrax Personnal Speech System (PSS) in the chair. Access to the PSS is via the computer. A BASIC program using ProDOS, called Speech COmmunication by Keyboard Entry System (S-COKES), was developed to allow both coded and direct entry of the words. The program allows access to disk files containing both code-to-word and word-to-code translation files. Additionally, messages may be printed out on a low-cost impact printer, a feature that is very useful for communication of longer messages, messages entered when the intended recipient is not listening, or when the synthesized speech cannot be understood.

While Alfie's communication is very holophrastic, he is almost always able to make himself understood when communicated with his parents,siblings and teachers. In time, it is expected that he will gain ability to talk with any English-speaking individual.

ELECTRICAL SYSTEM

Power is provided to all of the electrical/electronic units described in this paper from one 24-Volt bus that is connected to and fused (five Amperes) at the positive battery terminal. A main power switch on the power panel is used to switch power to the entire system. The bus to each sub-system (i.e. lighting, computer, synthesizer, accessory outlets) is individually switched via relays controlled from the the control keyboard, in series with manual switches on the electric power panel for the attendant override functions. A fuse is provided at the main bus terminal to each sub-system. Conservative fusing is essential to assure the chair occupant's safety and to protect the electrical and electronic componants. Electrical filtering is provided on the main bus and ZNR surge protectors are installed on each sub-system bus. Voltage regulators are provided for various units, as listed in the Table, while the lighting system consists of pairs of 12-Volt lamps connected across the 24-Volt bus. Provided it is charged nightly, the chair's 55 Ampere-hour capacity batteries provides an adequate source of power for both mobility and operation of all accessory systems.

CONCLUSIONS

For the individual who must reside in a wheelchair most of the time, the chair is his immediate environment for much of his life. With appropriately installed accessories, it can also become his extension to the world around him.

The first priority in any wheelchair, whether manual or powered, is comfortable, supportive seating. Once established, when physical limitations preclude manual operation of the chair, a powered chair is an essential means of mobility, providing the user has adequate dexterity and judgement to control the chair. In the case of Alfie, this was provided with immediate success, once an appropriately configured and located joystick was installed on his electric chair.

Once mobility had been demonstrated, it became obvious that a number of custom items could be installed to enhance the user's immediate environment while providing a communication link and near-environmental control.

As of this writing, several enhancements to the system described above are being developed- hence we call the chair as described in this paper the ALFIE I chair.

This work was solely done by the author and using the author's own funds and resources. It was done to help his son overcome some very difficult obstacles imposed by severe cerebral palsy, while showing what can be done to help the handicapped by applying sound engineering practices.

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AN INDEPENDENTLY ADJUSTABLE ATTACHMENT FOR A CABLE DRIVEN FLEXOR HINGE ORTHOSIS

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Rehabilitation Institute of Chicago

ABSTRACT

The design of an independently adjustable cable driven flexor hinge orthosis attachment for use by a person with C5 level quadriplegia is presented. The attachment mechanism allows the user to adjust the amount of tension present in the orthosis cable in order to allow lateral pressure reliefs, remove the discomfort in the shoulder musculature caused by the pressure of the shoulder harness, and allow maximum range of motion. Fabrication steps are included to make duplication of the design possible for attachment to a wheelchair armrest shroud and the backrest upright of a manual wheelchair having no armrests.

A person with a C5 level spinal cord injury may use a cable driven flexor hinge orthosis (CDFHO) to significantly increase functional abilities by achieving an active grasp and release. The CDFHO is a wrist hand orthosis with a dynamic wrist component. The wrist is flexed and extended by a cable mechanism, which is harnessed to the opposite shoulder, similar to the harnessing of an upper-extremity prosthesis. By elevating and depressing the shoulder, a three-point pinch is achieved.

The cable is typically secured to the wheelchair frame using a static hook attached with a hose clamp. The patient is unable to attach or remove this hook independently. This set-up has several disadvantages. Most importantly, it hinders the patient's ability to perform pressure reliefs in the wheelchair by restricting the patient from lateral or forward flexion positions. Second, the cable is taut, which maintains a constant pressure on the shoulder harness causing discomfort and fatigue in the shoulder musculature. Third, the typical hood system has also been found to limit active range of motion in shoulder flexion, thus restricting the patient's forward reach.

Due to these disadvantages, an attachment utilizing a ratchet mechanism was devised by RIC Rehabilitation Engineering. It allows for independent manipulation by the patient to achieve a change in the length and/or tension of the cable. This permits the patient to perform lateral pressure reliefs, alternate the tension placed on the shoulder musculature, and gain freedom for active range of motion in shoulder flexion.

DESIGN

The goals of the Adjustable Orthosis Attachment design included:

- providing the user with the ability to independently adjust the amount of tension present in the orthosis cable.
- attachment to existing manual and electric wheelchairs.
- low cost.
- durability.

The design replaces the static-type orthosis cable attachment with one that can be adjusted by the user. The user is able to adjust the amount of tension in the cable by moving a standard ratchet handle. The cable hanger, on its own cable, is coiled around the outside of the socket, and thus, can be adjusted (Figure 1).

FABRICATION

The fabrication of the Adjustable Orthosis Attachment requires the following materials:

- ratchet, 3/8 inch drive
- 7/16 inch impact socket, six-point type, 3/8 inch drive
- standard cable hanger
- orthosis cable (approximately 20 inches)
- cable housing (approximately 8 inches)
- housing attachment clips (two)
- attachment clip holders (two)
- 1/4"-20 x 5/8 inch round head machine screw
- 1/4" USS flat washers (two)
- 1/4"-20 lock nut (nylon insert)
- 8-32 x 1/8 inch set screws (six)
- aluminum collar 3/4 inch ID

Figure 1. **Adjustable Orthosis Attachment**

Fabrication of the Attachment can be broken down into the following steps:

1 - Drill and tap three holes (8-32 UNC thread) into the 7/16 inch socket at its hex head end. These three holes should be oriented at 120 degrees with respect to one another in order to allow three of the 8-32 set screws to hold the socket on the 1/4"-20 lock nut. A fourth hole should be drilled into the side of the socket approximately half way along its length to allow insertion of the orthosis cable. This hole can be drilled with the #29 drill used to drill the tap size holes for the set screws.

2 - Drill and tap three holes (8-32 UNC thread) into three of the sides of the 1/4"-20 lock nut. These holes should also be oriented at 120 degrees with respect to one another.

3 - Attach a standard cable hanger to the end of a 20 inch length of cable using a standard orthosis crimping tool.

4 - Install two cable housing clips on an 8 inch length of cable housing. Slide this housing onto the cable.

5 - Thread the cable through the hole half way along the 7/16 inch socket's body from the outside in. Attach a bulb of brazing material or tie a tight knot at the end of the cable. Pull the cable through the socket so that the bulb or knot comes up to the hole, preventing the cable from coming out of the socket.

6 - Locate the position on the wheelchair frame where the ratchet is to be attached. The ratchet must be located such that the user will be able to operate the ratchet along its full stroke length. For most wheelchairs, this may correspond to the armrest shroud. For other chairs, especially lightweight and sports models, a flat plane may have to be provided which will contain the pivot point. (Figure 2) Once the ratchet attachment point is provided, drill a body size hole for the 1/4"-20 x 5/8 inch screw.

7 - Install the 1/4"-20 x 5/8 inch round head machine screw in the hole drilled as the ratchet attachment point. Locate the 1/4 inch USS flat washers such that they "sandwich" the plane containing the ratchet attachment point. Install the 1/4"-20 lock nut on the screw and tighten so that the screw is stable in the hole but is still able to spin freely.

Figure 2. Rectangular aluminum provides pivot point plane

8 - Install and tighten three 8-32 set screws to fix the position of the lock nut on the machine screw.

9 - Attach the 3/4 inch aluminum collar to the socket at the end that attaches to the ratchet. This will prevent the orthosis cable from winding in the space between the socket and ratchet, which could force the ratchet off of the socket.

10 - Attach the ratchet to the socket. Make sure that there is no space between the aluminum collar and the ratchet.

11 - Place the socket on the 1/4"-20 lock nut and secure with three 8-32 set screws.

12 - Install the attachment clip holders such that the cable is directed upward toward the client's shoulder (Figure 3).

13 - Depending on the ratchet used, an extension may have to be added to the ratchet direction selector in order for the client to be able to control the tightening and loosening of the cable.

CONCLUSION

The Adjustable Orthosis Attachment has proven to be an effective way for a client to be able to independently control the tension present in a cable driven flexor hinge orthosis. (Figure 4). Advantages of this type of attachment over the standard static-type attachment include giving the

Figure 3. Cable Orientation

Figure 4. Client operating Adjustable Orthosis Attachment

user the ability to perform lateral pressure reliefs, (Figure 5) an elimination of tension placed on the shoulder musculature when the orthosis is not in use, and unrestricted range of motion in shoulder flexion. The design is able to be attached to a wide variety of wheelchairs as long as a flat plane is present at the location of the optimum ratchet attachment. The design is simple in nature and can be fabricated using tools available in most rehab engineering or orthotic shops.

SUPPLIERS:

- Hosmer/Dorrance
  561 Division Street
  P.O. Box 37
  Campbell, CA 95008
  (408) 379-5151
- McMaster-Carr Supply Co.
  P.O. Box 7690
  Chicago, Illinois 60680
  (312) 833-0300

Figure 5. Client performing lateral pressure relief

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CLINICAL APPLICATION OF THE ADJUSTABLE "COMPUTER CHAIR"

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ABSTRACT

The prototype of an adjustable fitting seat, which was designed and built to aid in body positioning and recording anthropometric data (See article 20.1, 1985 RESNA Proceedings, "Instrumented, Adjustable Seat for Evaluating Posture and Body Contours"), has been used in conjunction with the TIRR pressure evaluating pad as a clinical evaluation tool. The "computer chair" is being used to evaluate disabled individuals who have a history of skin breakdown problems related to seating. Data generated includes seated buttocks and thigh contours, as well as a pressure map of the seating surface. Hardware included on the chair also enables the clinician to quantify hip obliquity and rotation. The clinician then uses this data to aid in the prescription or fabrication of an appropriate seating device, cushion, or modifications.

BACKGROUND

In 1984, a chair was developed by Dr. S. I. Reger and a group of biomedical engineering students to be used in researching modular seating for wheelchair users. Specifically, it was designed to allow for complete adjustment relating to the subject's body dimensions, posture, and comfort. In so doing, the instrumentation tied to the chair would measure buttocks, thigh, and back contours, and buttocks and thigh seating pressures. Collection of this data was to serve a two-fold purpose. First, the anthropometric data would be of value to designers and manufacturers of wheelchairs and other mobility devices as a basis for appropriate hardware dimensions. Secondly, the instrumentation package would provide a mechanism for testing the effects of different types of cushions and body orientations on the disabled and non-disabled populations.

The adjustable fitting chair consists of a seating platform suppoorted in the front by metal legs which attach to the platform with steel hinges. The rear is supported by a hydraulic jack which allows the clinician to adjust overall chair recline while the patient is seated. The backrest is supported from the seat platform with hinges and a hydaulic jack to allow backrest recline adjustment independent of the seat. Arm rests are removable as well as adjustable in heighth, lateral position, and angle w/r to seat platform. Leg rests are independently adjustable for angle, and the foot rests can be adjusted for length and for plantar/dorsiflexion of each foot.

Chair instrumentation consists of an 8 X 8 matrix of linear potentiometers imbedded in the seat platform. As they sit in the chair, patients are supported by cushions with pre-drilled holes which allow probes from the 64 potentiometers to come in contact with the patients buttocks and thighs. Differentiation between potentiometer voltages caused by seating contours constitutes a representation of that seating contour. The 64 data points are rapidly recorded by multiplexed input to A/D converters on an LSI-11/23 computer.

Measurements of buttocks/thigh pressure are taken using various pressure transducers at the same time contour data is taken. Most notably, the pressure evaluation pad developed at the Texas Institute of Rehabilitation Research proves to be a practical addition to the instrumentation package when interfaced with the computer. The TIRR pad facilitates pressure measurements up to 100 mmHg, recorded in 144 locations under the buttocks and thighs.

METHOD

The potential of the adjustable computer chair as a tool for clinicians involved in

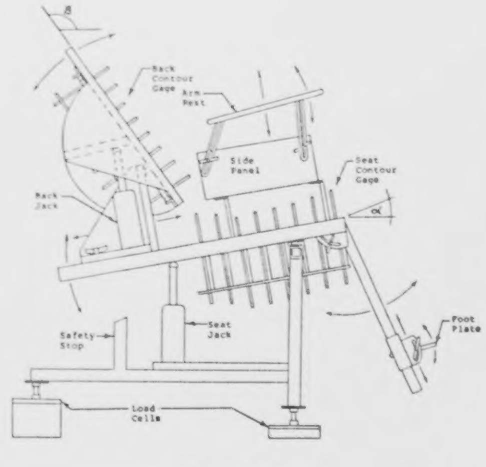

Figure 1
Schematic of adjustable chair.

seating evaluation was tested at the University of Virginia. As of this writing, fifteen patients from local health care facilities have been evaluated for seating changes using the computer chair. Two of those patients, and the results of their evaluations, are outlined below.

1) Mr. C. is a 40 year old male, T-12 paraplegic, 4 years post injury, weighing 190 lbs. He has good control and intact musculature in his upper trunk, and is also very active. Before his first visit to the seating clinic in September 1983, he had been hospitalized 4 times within two previous years for surgical treatment of ischial sores.

Through clinical evaluation using the computer chair, it was determined that there was no single seat cushion available which would reduce Mr. C.'s peak pressure (over 75 mmHg), which occurred near the ischial tuberosities and greater trochanters. The alternitave was to creat a custom cushion for the patient using two 3-inch pieces of high-resilience polyurethane foam laminated together. This 6-inch cushion was then carved out in the high pressure, high contour areas dictated by the computer chair data to help reduce load in those areas. Subsequent interface pressure readings showed 55 and 60 mmHg at the ischial tuberosities and greater trochanters, respectively.

2) Ms. G. is a 35 year old female, T-1 paraplegic from transverse myoltis at age 3, and weighs 115 lbs. She came to the seating clinic, accompanied by her physiatrist and therapists, after discharge from surgery for treatment of iscial and sacral sores. Ms. G. had undergone bilateral isciectomy and girdle stone proceedures, which made it imperative that her lower extemities be properly positioned during sitting to prevent shearing of buttocks and thigh tissues.

Overall adjustability of the computer chair allowed the clinicians to evaluate the effects of, not only various types of seat cushions, but levels of seat and back recline. Leg rest adjustability also permitted easy accomodation of the patient's particular lower extremity support needs. After testing various combinations of body position, recline, and cushion type, results of the evaluation showed that a 3 inch polyurethane "345" foam for seat cushion was most appropriate when incorporating a back angle 100 degree inclination to the horizontal. With a sheepskin cover, this cushion and back angle afforded this woman the best seating support for providing peak pressure reduction, heat dissipation, trunk stability, and comfort.

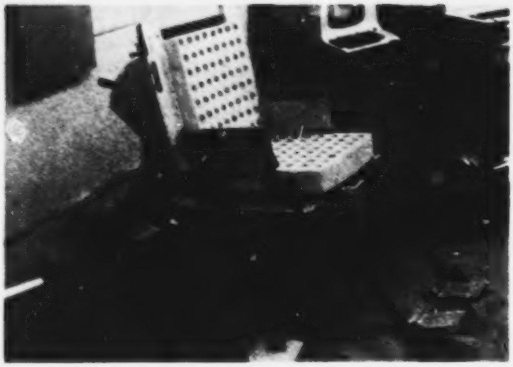

Figure 2
The Adjustable Computer Chair

RESULTS

Since Mr. C.'s initial evaluation, he has experienced no recurrence of pressure sores. Ms. G. has experienced no pressure sores related to seating since her last clinical visit, as well. Certainly, the adjustable computer chair played no active role in preventing recurrence of pressure problems in these two patients. However, its instrumentation and flexibility allowed the evaluation of many different parameters related to seating. In analyzing this data, the rehabilitation team was then able to make a more informed decision as to what seating system was most appropriate for that patient.

DISCUSSION

As mentioned previously, the adjustable computer chair was originally designed as a research tool, not as a clinical tool. As such, some of its mechanisms were not designed with repetative use and adjustment in mind.

The arm rests of the computer chair , while completely adjustable, offer a support surface only one and one-quarter inches wide. They are each supported by two friction wingnuts which are ineffective in offering stability during transfer into the chair. Friction nuts are also used to allow adjustment of leg and foot rests. They sometimes slip out of adjustment.

In the interest of easier patient transfers it may be appropriate to incorporate a mechanism to raise and lower seat heighth in the computer chair. Currently, seat heighth is set at 26 inches, which for many patients is to great of a hurdle over which to transfer.

Finally, it has been suggested that in order to more closely duplicate some of the dynamics involved in wheelchair seating, it might be prudent to add on removable wheels that the patient could push on, much like he/she would do when propelling his/her own chair. This would facilitate the collection of pressure and contour data that would more closely resemble what the patient's skin was going through during daily transit in their chair.

All of the above modifications are being investigated, and plans are being made to implement those deemed most suitable in elevating the utility of this research device to the status of a clinical instrument.

CONCLUSIONS

The adjustable computer chair has the potential to be an effective clinical device for aiding in the evaluation of seating needs for the disabled. It allows the simultaneaous collection of seating pressure and contour data, the quantification of postural irregularities, and can show the effects of changes in body position, recline, and cushion type on these parameters. With minor modifications to accomodate more rigorous clinical use and to expand its dynamics measurement capabilities, the adjustable computer chair can be a clinical aid that minimizes the guess work aspects of seating prescription.

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583

A HEAD BAND SYSTEM FOR ANTERIOR HEAD SUPPORT IN A SEATING SYSTEM

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ABSTRACT

One of the areas in seating which can cause clinicians great distress is in positioning of the head and neck. The individual who actively pulls or falls into head flexion provides a difficult problem in seating.

The University of Tennessee, Memphis - Rehabilitation Engineering Program has fabricated one inexpensive and cosmetic solution to this positioning problem. Used in conjunction with a seating system with a neck collar or head rest, it has provided upright positioning thus far for 25 individuals with head control problems.

The wheelchair seating system is a carefully balanced system of components designed to provide external support for the individual who because of lack of neuromotor or neuromuscular control, cannot independently maintain a seated posture. Over the past 10 years, many approaches which allow fabrication of seat and back components have been produced, helping solve trunk and pelvic positioning problems. One of the areas in seating which can cause clinicians the greatest problem is in positioning of the head. The individual who consistently falls or pulls their head in flexion provides a very difficult problem in seating.

Very often, these are severely retarded individuals or individuals with visual impairments who do not receive cortical input that assists in maintaining an upright head position. Some have very poor head control because of hypotonicity in the trunk/neck musculature, resulting in a hyperextended or flexed head position. Reflex activity or a dominance of flexor tone can also cause this "head-hanging" position. Allowing this position to continue usually results in a very hyperextended position of the head due to overstretching of the neck extensors. In those individuals who are able to be functional, this head position can prevent them from functional and energy-efficient access to technical aids.

Many anterior devices, such as halos and head straps have been tried. These are sometimes successful, but the individual can often hyperextend their head and come out of the device, or the strap slides on the head as they pull forward until the strap falls off. Soft cervical collars, chin supports, and collar/vest type supports are other solutions, but are not always appropriate (particularly with individuals with swallowing difficulties), can be bulky, uncomestic and can be costly.

An inexpensive, comestic alcernate solution has been fabricated and used at the University of Tennessee - Rehabilitation Engineering Program (UTREP) with approximately 25 individuals having the above mentioned head control problems. The objective of the device was to allow the head (in conjunction with a full seating system) to be held in an upright position. The device had to have some adjustability to allow some movement of the head in an anterior/posterior plane when appropriate. It had to be as unobstrusive to the individual's appearance as possible, and be able to be easily attached and removed. The head strap consists of a one to two inch piece of webbing covered with a fabric covering for comfort, fitted around the circumference of the individual's head, just above the ears. A smaller piece of webbing is attached perpendicularly to either side of the strap and placed superiorly over the head to prevent it from slipping down over the eyes. A strap is sewn to the back of the circumference strap to provide a posterior and downward force at the back of the head. An adjustable 4-bar buckle attached to this strap allows adjustment of the head position so the individual does not need to be held against the head rest all of the time (Figures 1 and 2). This head strap has been used in conjunction with an Otto Bock neck collar and 2-step head rest, and the Shapeable Matrix Seating System.

Thus far, with select individuals, the strap has stayed in place and prevented the "head-hanging" position with the 20 individuals. With two individuals who were microcephalic, a snapped chin portion (chin strap from an athletic store) was used to keep the strap from slipping off the top of the head.

The chin strap has proven to be one inexpensive (approximately $20.00) cosmetic solution to the problem of anterior head support.

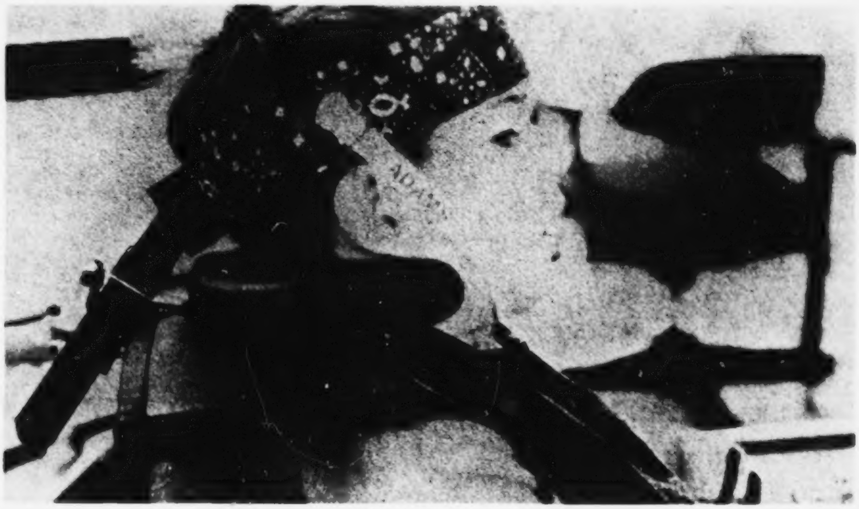

FIGURE 1.

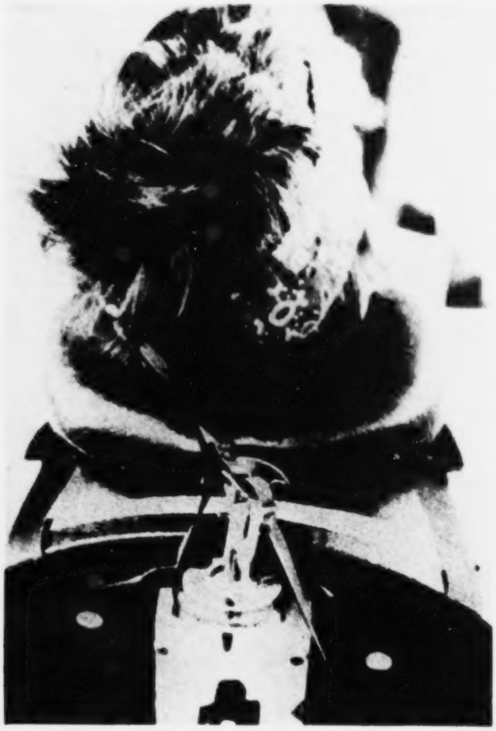

FIGURE 2.

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THE MERU RIGID PELVIC STABILIZER FOR POSTURAL CONTROL

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ABSTRACT

In the provision of specialized seating for postural control, stablization of the pelvis is essential to obtain effective control of more distal parts of the body. Though there are several techniques for enhancing pelvic stabilization, until recently there were no effective means of maintaining pelvic orientation for the more challenging seating problems. After consideration of the mechanics of pelvic malalignment, developers at the Medical Engineering Resource Unit (MERU) devised a rigid pelvic stabilization system similar to those of Margolis et al (1985) and Shaw (1985). Evaluation of the MERU system demonstrated its effectiveness in maintaining pelvic position and orientation for adults and children and defined its limits of applicability.

INTRODUCTION

In the provision of postural control through seating, providing a stable pelvis is essential. A stable pelvis is the keystone to controlling the posture of the rest of the body. Along with stability, the orientation of the pelvis is critical. Keegan (1953) demonstrated radiographically that lumbar curve in the sagittal plane is affected by pelvic tilt and hip flexion. The pelvis should be oriented as squarely as possible with consideration of the individuals contractures and spinal deformity.

The consequences of pelvic instability are detrimental to people requiring posture and pressure control. If the pelvis position or orientation shift from their designated locations, then the trunk, upper limbs and lower limbs move with respect to seat hardware. Malalignment of the seat corrective hardware renders it inefficient or harmful. When contoured seat cushions are used for pressure control, pelvic displacement will cause pressures to be increased in undesirable areas and reduced in areas that can tolerate higher pressures.

Many of the disabled who do not have appropriate posture, develop functional deformities rapidly. These deformities result from prolonged inappropriate positioning. It is not uncommon for long term care patients to be sat in wheelchairs in a good posture then left for gravity to take its course. Invariably, the patients end up in postures that compromise their function and well being. It is not uncommon for individuals to be left like this for hours at a time. The prolonged periods of time in these postures lead to the formation of contractures and ultimately structural deformities.

STABILIZATION TECHNIQUES AND EQUIPMENT

No stabilization

The least amount of postural stability is when the person is sitting on a water or air floatation type cushion. These cushions are usually effective in equalizing pressures under the buttocks, but they leave the pelvis free to tilt, rotate and shift position.

Hip belts are often used in conjunction with these cushions. They do very little to remedy the problem. As with any padding under or behind the buttocks, the cushion can be compressed to enable the pelvis to slide under the belt. In general, firmer cushions result in better stabilization.

Pelvic belts

The most common form of pelvic stabilization is to provide a pelvic restraint belt at 45 to 90 degrees from the seat bottom combined with a snug lateral fit in the pelvic area. The strap holds the pelvis back and down by applying pressure to the anterior ilium and proximal thighs. The belt effectively stops anterior tilt of the pelvis but is limited in stopping posterior tilt, obliquity and rotation.

To be effective, the pelvic strap has to be taut and not give at all. Not much slack is required to make the strap ineffective. When using pelvic straps that have a length adjustment, the patient does not have to be right back in the seat before the strap is done up. Thus, care givers unaware of the need to have the patient's buttocks all the way back in the seat can unknowingly position them inappropriately. The most significant component in ensuring consistant results is the education of care givers.

Wedging or reclining

Gravity can be used as an assit to keep the pelvis back in the seat by altering the seat's orientation in space or by raising the distal thighs. This must be weighed against changes to the patients' visual field, their ability to interact socially, and potential adverse effects on spastic activity of patients with central nervous system impairment.

Anti-thrust block

The anti-thrust seat was first reported by Siekman in 1983. It has a bar of firm foam located immediately in front of the ischial tuberosities. The firm bar is intended to stop the inferior bony prominences of the pelvis from sliding forward. This technique is helpful for most posterior pelvic tilt problems.

In its present format, the anti-thrust seat is dependent on hip straps for controlling the anterior superior aspects of the pelvis. This is something that hip straps do not do very well. Thus, effectiveness of the anti-thrust bar is limited when strong or asymmetrical hip extension is present.

Mulholland pelvic stabilizer

The stabilizer component of the Mulholland Growth Guidance System is quite different than those previously described. It consists of adjustable lateral pelvic supports and a stiff pommel that inserts between the legs and presses against the pubic crest. To be effective, the stabilizer must be positioned close to the pubic crest. Timid care givers often do not insert it sufficiently making it ineffective.

The Mulholland pelvic stabilizer is generally very effective in limiting posterior pelvic tilt but it is not effective in stopping axial pelvic rotation. Recently Mulholland has added ASIS (anterior superior iliac spine) pads. These are similar to the Mulholland shoulder pads and are intended to press on each ASIS to stop rotation.

University of Tennessee rigid pelvic restraint

The rigid pelvic restraint developed by Greg Shaw (1985) at the University of Tennessee, consists of a rigid pelvic band that attaches to the seat bottom by seat belt buckles, (figure 1). In comparison to pelvic straps, the rigid restraint has been shown to improve pelvic stabilization for severe athetoid cerebral palsied children and young adults when used in conjunction with firm intimate fitting seat cushions.

An advantage of rigid pelvic restraints is that the patient must be positioned completely back in the seat before the restraint can be attached, thus ensuring the desired alignment. The developers found that 1/8 to 1/4 inch adjustments caused significant changes to the device fit and function.

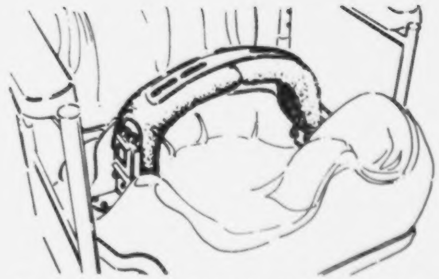

Figure 1: The U of T rigid pelvic restraint, (from Shaw, 1985).

SubASIS bar

At the University of Wisconsin-Madison, Margolis et al (1985) have also developed a rigid pelvic restraint. It consists of a round padded bar that fits transversely immediately below both ASIS.

As with other rigid pelvic restraints that have only one attachment position, the subASIS bar ensures reproducible positioning. The subASIS bar must be used in conjunction with a well designed seating and positioning system with a firm seat and lateral hip pads.

THE MERU RIGID PELVIC STABILIZER

At the Medical Engineering Resource Unit (MERU) of the University of British Columbia the authors have developed another rigid pelvic stabilizing system. The MERU system incorporates a padded subASIS bar similar to that of Margolis, with the addition of a bend to remove pressure from the lower abdomen. The stabilizer was evaluated in 3 formats. One format is for use in conjunction with existing seating and positioning wheelchair insert systems, (figure 2), another included alternate attachment mechanisms for use with the Mulholland Growth Guidance System, the third provided posterior and lateral pelvic support for when no positioning system is present, (figure 3).

The MERU system was evaluated on 10 children and 10 adults. The seating problems presented by these clients included passive and spastic hip extension, poor righting reactions, pelvic obliquity, and fixed pelvic, spinal and hip deformities. All the clients included in the evaluation did not have sufficient pelvic stabilization in their existing seating systems.

One objective of the evaluation was to find the limits of applicability of the stabilizer, therefore, subjects for which there was little chance of success were included. The other objective of the evaluation was to identify potential improvements to the stabilizer system.

The MERU stabilizer was effective in 14 of the 20 trials. The 14 successes were for a wide range of moderate to severe seating problems. Of those that were not sucessful, 1 was soluble by minor design changes, 1 was unacceptance by the user, the remaining 4 were due to excessive pressures exerted by the bar.

The pressure related problems were as follows:

> On one patient with multiple sclerosis, the large pressures were the result of strong knee flexion spasms. The therapist's desire to maintain knee extension were not compatible with managing pelvic orientation.
>
> An adolescent with cerebral palsy had extremely strong extension spasms. When in spasm he destroyed the padding on the subASIS bar until he was pressing on the metal tubing.
>
> Two elderly gentlemen with cerebral palsy propelled themselves in their wheelchairs using their feet. The constant motion of propulsion gradually wedged them under the bar eventually causing hazardous pressures. Redesign of their seating systems could possibly lower them sufficiently to remedy this problem.

In general the stabilizer is showing results similar to other rigid pelvic restraints. Consistent positioning is ensured, pelvic stabilization is better than with non-rigid systems, and frontal ingress and egress are no more difficult than with other systems. In addition, it is possible that the MERU system which provides posterior and lateral support, (figure 3), will stabilize the pelvis when used in conjunction with pressure equalization cushions.

Use of the MERU system is continuing at Sunny Hill Hospital in conjunction with other stabilization techniques. The MERU system is preferred in a large portion of the instances where stabilization is problematic. Design improvements are being made on an ongoing basis.

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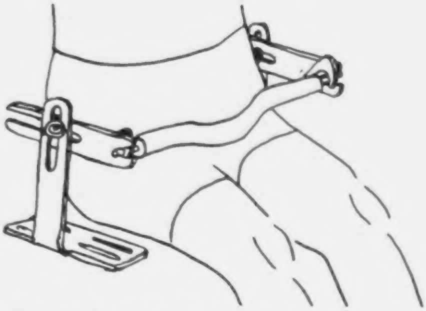

Figure 2: The MERU stabilizer for use with a positioning system.

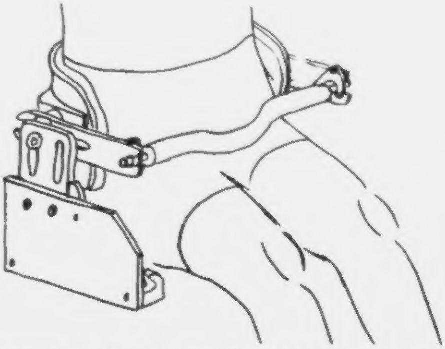

Figure 3: The MERU stabilizer for use without a positioning system.

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THREE DIMENSIONAL MACHINING OF CUSTOM CONTOURED POLYETHYLENE FOAM CUSHIONS

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ABSTRACT

A prototype system to machine a block of polyethylene Ethafoam into an accurate custom contoured foam cushion has been developed. This system traces a generated surface reproduction of the buttocks and thigh region and correctly aligns a rotating cutter by means of a mechanical linkage. The cutter then machines the foam block to create a custom cushion with a contour that is accurate to within ± .040 inches to that of the traced surface.

INTRODUCTION

The need for customized foam cushions is great, and the present process of fabricating these cushions is inefficient and outdated. It is a multi-step procedure where the patient first sits in a beanbag chair to obtain an imprint of the body contour. From this, a plaster cast can be made which the technicians use to develop contours for hand carving the foam seat. Because of the inaccurate contour replication produced by the beanbag impression, a series of trial fittings are needed. During trial fittings, therapists look for red spots that may appear on the patient's skin, indicating high pressure areas created by the cushion. Left untreated, these red spots can lead to infection and other medical problems. Also, the hand carving stage is very time consuming, which results in a long wait on the patient's part for a much needed customized seat.

Last year, a student team from Worcester Polytechnic Institute developed a system for Newington Children's Hospital (N.C.H.) in Connecticut to create custom cushions for the buttocks and thigh region using a unique method of even pressure distribution created by a pin matrix, as shown in Figure 1. The end result was an extremely promising method to reproduce body surfaces and a method to create a foam cushion through foam injection. The urethane foam used for their foam injection process, however, did not have the desirable qualities of polyethylene Ethafoam which is currently being used a N.C.H.

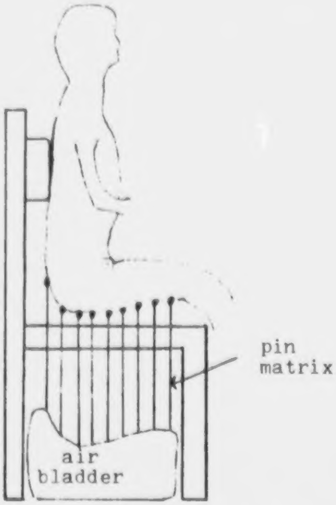
The ideal process of creating custom foam seating would be to carve a block of the desirable Ethafoam into a seat by duplicating the three-dimensional surface created by the pin matrix process. To achieve this, a method of three-dimensional surface replication is needed.

Current methods of reproducing three-dimensional surfaces tend to be extremely complex. They often involve computers, laser technology, or other highly technical equipment. All of these methods, however, are very complex and expensive.

Considering all of the previously mentioned facts, it is the goal of this project to create a mechanical method to produce a customized Ethafoam seat using three-dimensional body surface replication.

METHODOLOGY

In the initial project stage, several methods of fabrication were considered and later discarded for various reasons. One such method considered was to surround each pin with a heating element, which would be pressed into the foam block. The heated pins would melt holes in the foam block, thus creating depth gauges for a hand cutting operation to produce a cushion. This method proved to be far



BODY SURFACE REPRODUCTION
FIGURE 1

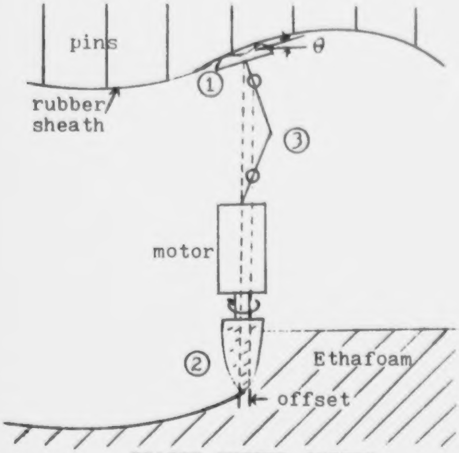
too inaccurate while also being very time consuming due to the hand cutting involved. Potential safety problems were also apparent.

Another method considered was to use a Computer Numerical Control (CNC) milling machine. Although this would produce an accurate cushion, a CNC system would require involved high-level computer programming for pin depth measurements, surface generation, and the actual cutting process. These problems, along with the expense of a computerized system, make this method unfeasible.

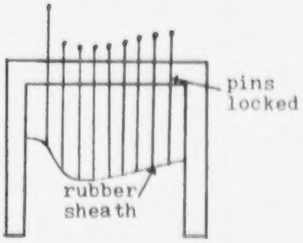
The method of creating an Ethafoam cushion by a rotating cutting tool was found to be most appropriate and feasible. This system consists of three parts, as shown in Figure 2:

1)A tracer head to follow the contour of the surface.
2)A motor with rotating cutting tool.
3)A linkage that properly aligns the cutting tool, which is dependent upon the inclination of the tracer head.

By moving this tracer-cutter apparatus along a surface, a block of polyethylene Ethafoam can be machined out to create a custom contoured foam cushion. To correctly align the cutter, a seemingly simple yet theoretically complex linkage was designed. This linkage traces the surface created by a rubber sheath stretched across the pin matrix and forms a smooth surface for the tracer head, diagrammed in Figure 3. The linkage moves the motor and cutter into the proper position so the cutter is machining the foam exactly below the point of contact of the tracer. In doing so, the linkage must move the motor and cutter properly to compensate for the necessary offsets created between the tracer and the cutter.



TRACER-CUTTER SYSTEM
FIGURE 2

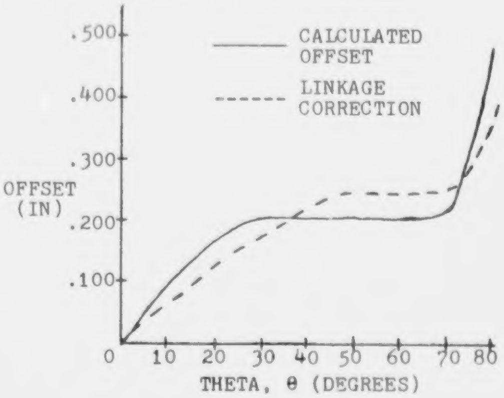


CREATING THE TRACING SURFACE
FIGURE 3

To cut out an entire foam seat, a method has been developed whereby the tracer is allowed to follow the three-dimensional surface created by the rubber sheath. This is accomplished by attaching a tracking system to the seat frame which moves in two axial directions, thereby covering an entire horizontal plane. The motor is then attached to constant force linear springs which allow the motor and cutter system to move vertically, independent of the horizontal plane. Thus, a three-dimensional surface replication system is created.

RESULTS AND CONCLUSIONS

The goal of this project was achieved; a method was found to use the desirable polyethylene Ethafoam foam currently being used at N.C.H. for custom contoured foam seating. With the aid of computer programs to calculate



TOTAL CUTTING ERROR
FIGURE 4

cutting error and other data, a linkage design was obtained that brought the total cutting error of the system within ±.040 inches at all times, as shown in Figure 4. This diagram was created by graphing the necessary offsets and the linkage correction per angle degree of theta, as shown in Figure 2.

The entire system is small enough that with partial disassembly, it could be easily transported. This would eliminate the need for patients to be transported to a central location for fitting of their custom foam seat cushions. This system could be brought to the patient's home, and the custom cushion could be made there. In cases where patients must travel far distances, or travel itself is extremely difficult due to their handicaps, portability would be most important.

This system achieves the goal of the previous project of creating a finished seat cushion within one hour. This finished customized cushion has a three dimensional surface profile that is within ± .040 inches of the desired surface. No hand carving technique could achieve this accuracy in any reasonable amount of time. The system was designed as a surface replicator, so there are no limitations for it's use on other parts of the body; or other applications.

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ACKNOWLEDGEMENTS

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First National Triathlon for the Physically Challenged

Anne Marie Glenn M.D. Spinal Cord Injury Center, V.A. Medical Center
Palo Alto, California, Kenneth C. Wright, Programmer/Analyst, Stanford
University, Palo Alto, California

An increasing number of individuals are participating in organized sports and recreational activities, this includes able-bodied and physically challenged. Triathlons have traditionally been one of the most demanding sports contests consisting of not one but three events: swimming, cycling and running. Although distances may vary and team entries have become increasingly popular utmost respect goes to the true "ironmen" , those who complete the entire event. On August 31, 1986 at Stanford University in Palo Alto, California, the First National Triathlon for the Physically Challenged took place. This event was specifically designed for wheelchair athletes (or able-bodied competing under the same conditions and using similar equipment) and consisted of the three standard events: swimming (400 yards for quadriplegics and 800 yards for all others), hand-powered cycling (10K), and a wheelchair road race (5K). Competitors consisted of paraplegics,quadriplegics, amputees and a few adventurous able-bodied. Participants came from Texas, Tennessee and California to compete in this unique event. Only Ken Wright, a IB quadriplegic, completed the entire event, thus being the only true "ironman". Such an event, in addition to being the first of its kind, provided an opportunity for comparison of equipment and training techniques as well as increasing awareness in the community of the abilities of these athletes. Triathlon results will be presented in addition to photographic representation.

A special thanks to Verne Scott and the Triathlon Federation (Trifed) for their support of our endeavor.

Additional info and next year's event:
Second National Tiathlon
P. O. Box 1484
Cupertino, California 95015
(408) 255-8396

Special Interest Group 10

Electrical Applications

Chair: Andrew Shoenberg, Ph.D.

RESTORING FUNCTIONAL MOBILITY TO PARAPLEGICS

Felix E. Zajac
Scientific Symposium Chairman
Rehabilitation R & D Center
Palo Alto VA Medical Center
Mechanical Engineering Dept.
Stanford University

One application of electrical stimulation is for use in exciting paralyzed musculature to restore functional standing, walking, and stair climbing in paraplegics. While remarkable progress is being made to accomplish these goals, there still exist a myriad of technical and clinical problems that need to be solved before such functional neuromuscular systems become commonplace in clinical practice. This Symposium, actually Panel Discussion, is organized not only to define some of these major and minor problems, but also to discuss potential solutions. It is hoped that this Panel Discussion will lead to candid discussion on this important topic.

The Panel will consist of seven scientists, engineers, and clinicians actively working in this area. The format of the panel discussion will be to have each member respond to questions presented by the Moderator and the Chairman of this Panel Discussion. Questions will be solicited from all panel members prior to the conference, and those selected by the Chairman for discussion at the conference will be known to all panel members prior to the conference. At the conference, each panel member will give a brief answer to the specific question on the floor. The panel menbers will then engage in frank discussion on this specific question, followed by open discussion among the audience on this specific question.

Examples of questions that may be asked are:

1. What functional assessment and evaluation should be performed on paraplegics prior to subject participation in these research and development projects?

2. What are the potential risks and benefits to the paraplegics participating in these research and development projects?

3. How should muscles be stimulated? Which muscles? How many muscles?

4. What sensors are minimally needed? What algorithms for controlling stimulation of muscles should be used?

5. Does the attainment of the overall objective (i.e., to restore functional mobility to paraplegics vis a vis electrical stimulation) require the establishment of a consortium among the existing (and other) research groups working in this area with, for instance, each research group of the consortium reporting to the same central authority?

The Panel Members will be:

Howard J. Chizeck, Ph.D.
Systems and Biomedical Engineering Dept.
Case Western Reserve University

Roger M. Glaser, Ph.D.
Department of Applied Physiology and Biomedical Engineering
Wright State University

Robert J. Jaeger, Ph.D.
Pritzker Institute of Medical Engineering
Illinois Institute of Technology

Alojz Kralj, D. Sc.
Electrical Engineering Dept.
Edvard Kardelj University

E. Byron Marsolais, M.D., Ph.D.
Chief, Rehabilitation Medicine Service
Cleveland VA Medical Center

Donald R. McNeal, Ph.D.
Director, Rehabilitation Engineering Center
Rancho Los Amigos Medical Center

Robert L. Waters, M.D.
Chairman, Dept. of Surgery
Rancho Los Amigos Medical Center

The Moderator will be:

Simon Levine, Ph.D.
Dept. of Physical Medicine and Rehabilitation
University of Michigan Medical Center

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Felix E. Zajac, Ph.D.
Rehabilitation R & D Center (153)
Veterans Administration Medical Center
Palo Alto, CA 94304

NEUROPROSTHESES: PAST, PRESENT AND FUTURE TRENDS

Felix E. Zajac
Scientific Symposium Chairman
Rehabilitation R & D Center
Palo Alto VA Medical Center
Mechanical Engineering Dept.
Stanford University

Neuroprostheses are under development to restore function in persons with sensory and motor disabilities. The application of electrical stimulation to restore functional use of paralyzed extremities, such as standing and walking in paraplegics and hand manipulation in quadriplegics, are examples of neuroprostheses frequently discussed and presented at RESNA Conferences. However, there are equally exciting applications of electrical stimulation used in the development of other neuroprostheses, which RESNA participants may not be aware. This Symposium is organized so as to take the audience on a chronological tour of the development of four of these neuroprostheses. Specifically, the objectives are to inform the audience of the basic function of the specific neuroprosthesis under discussion, why this neuroprosthesis was chosen for development, the technical and clinical problems encountered during its development, and how solutions to these problems were or are being found.

The specific neuroprostheses to be presented are:

1. Overview: Perspective of neuroprostheses in general, and elements common to all neuroprostheses, including the development of safe and reliable stimulating and recording electrodes (Hambrecht).

2. Cochlear Prosthesis: This neuroprosthesis (electrical stimulation of the cochlear or cochlear nerve to restore hearing to the deaf) represents one that has advanced to the point where it is under multi-commercial development (White).

3. Bladder Prothesis: This neuroprosthesis (electrical stimulation of nerves and the spinal cord for treatment of urinary incontinence) represents one that is undergoing clinical trials and close to commercial development (Tanago and Schmidt).

4. Ejaculation Prosthesis: This neuroprosthesis (electrical stimulation of pelvic sympathetic nerves to restore or assist penile erection and seminal ejaculation in males with spinal cord injury) is one that is under development and undergoing preliminary clinical trials (Perkash).

5. Visual Prosthesis: This neuroprosthesis (electrical stimulation of either the optic nerves, or of visual sub-cortical or cortical structures, to restore sight to the blind) represents one that is still in an early stage of development (Hambrecht).

The speakers will be:

Frederick T. Hambrecht, M.D.

Head, Neural Prosthesis Program
National Institute of Neurological and Communicative Disorders and Stroke
National Institutes of Health

Inder Perkash, M.D.
Chief, Spinal Cord Injury Service
Palo Alto VA Medical Center

Richard A. Schmidt, M.D.
Associate Professor
Department of Urology
University of California, San Francisco

Emil A. Tanago, M.D.
Professor and Chairman
Department of Urology
University of California, San Francisco

Robert L. White, Ph.D.
Professor and Chairman
Electrical Engineering Dept.
Stanford University

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Felix E. Zajac, Ph.D.
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NEUROPROSTHESES: PAST, PRESENT AND FUTURE TRENDS

Richard A. Schmidt, University of California, San Francisco

NEUROPROSTHESES: PAST, PRESENT AND FUTURE TRENDS

Many benefits have been observed in patients implanted with neurostimulation devices - restoration of continence bladder evacuation, enhanced tissue integrity, etc. This paper discusses the U.C.S.F. experience in the past 5 years. One hundred and twenty patients have received electrode implants to restore voiding continence or simply treat symptomatic voiding dysfunction.

TREATMENT OF SPASTICITY

It is well established that neurostimulation minimizes or decreases spastic behavior. Used properly, it becomes very useful in modulating spastic voiding dysfunction. Most patients with voiding problems fall into this category, especially those with multiple sclerosis, stroke, hydrocephalus, cerebral palsy, and injuries of the cervical and thoracic vertebral spine. Incontinence secondary to precipitate voiding or unsuppressible urge are typical in these patients. They may or may not be able to empty their bladders completely.

Detrusor activity is suppressed by sphincter contractions (Fig. 2). Thus, enhancing tone within the external sphincter suppresses the detrusor and improves storage. Patients are tested for this response by placing a temporary wire electrode into the 3rd sacral foramen. Contraction of the pelvic sphincters provides visual evidence of a good couple with the nerve. An electrode can then be left in the foramen for several days to allow assessment of control of precipitate voiding. Because the thresholds for somatic nerves are much, much lower than those for autonomic nerves, selective stimulation of the sphincters can be achieved without dyssynergic contractions of the bladder. In spinal injury patients, it is extremely difficult to elicit a detrusor contraction with stimulation because of the inhibitory effect that the sphincter contraction has on the bladder (Fig. 2). Thus, the amplitude of stimulation may exceed the threshold for producing detrusor contraction, but no activity or suppressed activity is seen because of the overriding effect that the sphincter has on the bladder's ability to contract and empty. This inhibitory effect of the sphincter contraction can be used therapeutically where the goal is to achieve continence through suppression of an unstable bladder. It is a natural reflex used by everyone to maintain convenience of bladder evacuation. It is important to test all patients urodynamically and to monitor responses obtained from stimulation. Many patients, incontinent because of unstable bladder or rectal behavior, may become continent after the application of a continuous or intermittent train of pulses that causes sphincter muscles to contract. The stronger the muscle contractions, the greater the inhibition or stabilization of detrusor activity.

BLADDER EVACUATION

To achieve a low pressure evacuation of the bladder, active sphincteric resistance caused by stimulation must be eliminated and passive resistance must be reduced (Fig. 3). Both goals have been achieved in animal experiments through selective sectioning of somatic nerves. The human pelvic nerve anatomy is extremely complicated and poorly understood. Difficulty in applying the animal model to humans has thus far frustrated efforts to eliminate active closure of the urinary sphincter with stimulation of the human sacral roots. Thus far 20 patients have received implants of arrays of electrodes around the sacral roots. Each has had a different arrangement of electrodes. The reasons for the variations among arrangements are unique to each.

Despite this uniqueness, the following observations have been made from the evaluation, implantation, and follow-up of these patients: Exposure of the sacral nerves extradurally is uncomplicated. It is possible to separate the S-3 ventral roots from the S-3 dorsal root using microdissection. Voiding was produced only as sphincter resistance was greatly reduced with xylocaine blocks on the pudendal nerve preoperatively and subsequent severing of selective somatic nerve sections after electrode implants. Bladder responses to stimulation were better after pudendal block than before. This suggests that sphincter stimulation inhibits bladder contraction and argues against the success of poststimulation voiding techniques. Rarely, reflex voiding could be triggered by the sphincter contraction-relaxation resulting from stimulation. This response was, however, unpredictable and highly variable and, thus, could not be applied successfully to achieve evacuation of the bladder. Unilateral pudendal neurectomy had no impact on bladder-sphincter dyssynergia after 3 months, and no changes in rectal continence or erections were apparent. The reflex excitability of these functions, however, diminished. The erections also remained essentially unchanged after unilateral somatic nerve section, although frequency and duration and spontaneity seemed subjectively diminished, however slightly. All patients have benefited chiefly through improved control over bowel and bladder, and successful voiding from the bladder itself was achieved in three patients in the past year (Figs. 4 and 5). Autonomic dysreflexia could be precipitated in patients whenever detrusor-sphincter dyssynergia was induced by neurostimulation. Synchronous voiding, after the detrusor response was separated from the sphincter, was accompanied by only slight elevations in bladder pressure in these patients.

TABLE I

I. **Female Dysfunctional Voiding Syndromes**:
Pelvic and Urethral Pain Syndromes
Urge-Frequency Syndromes
Interstitial Cystitis
Urinary Retention
Total Patients: 38
Significantly Benefited: 73%
Insufficient Follow-up: 9
<25% (8) >50% (3) >75% (7) >90% (12)
Failures: 8 Successes: 22

II. **Post-Prostatectomy Incontinence**:
Secondary to Instability
Secondary to Weakness
Secondary to both Instability and Weakness
Total Patients: 18
Benefited: 50%
<25% (9) >50% (3) >75% (3) 90% (6)
Failures: 9

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ENHANCEMENT OF ULCERATED TISSUE HEALING BY ELECTRICAL STIMULATION

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Rajko Turk*, Alenka Kolenc, Stanislav Reberšek
Faculty of Electrical Engineering, *University Rehabilitation Institute,
**Jožef Stefan Institute, Edvard Kardelj University,
Ljubljana, Yugoslavia

ABSTRACT - The effects of biphasic current stimuli on healing of decubitus ulcer in paraplegic patients are presented. Four sacral wounds and five wounds over trochanter major were treated with electrical stimulation. Classical treatment was applied to two sacral and two wounds over trochanter for four weeks. After this period, electrical stimulation was applied to the control wounds as well. It was shown that the healing process, once triggered, has an exponential behaviour. The rate of healing was for trochanter wounds twice as rapid as for sacral wounds. Hence, the time constant of decreasing sacral wound area is 2.4 weeks and for wounds over trochanter 4.7 weeks. It seems that the rate of healing strongly depends on the location of the wound. Up to the present, a lack of data regarding time hystories of wounds treated by classical treatment has not yet allowed statistical comparison of results obtained by stimulation and classical treatment.

INTRODUCTION

Electrical stimulation appears as a promissing method in prevention (1) and treating (2-6) of pressure sores. The first investigator to propose that natural fields might influence soft tissue growth was Albert Mathews (7). In 1903 he discovered potential gradients along the surface of regenerating hydroids. A review of the knowledge about the natural, steady electrical fields, involved in the control of growth and development of cells and tissues, was done by Jaffe and Nuccitelli (8). The association of current with healing led to considerable efforts to enhance soft tissue healing by electrical stimulation. The results of animal experiments also showed differences in quality of healing: the wound strength of unstimulated wounds was consistently less than stimulated wounds (9). However, obtaining the quantitative data and statistical analysis of the results is complicated due to the variety of pathophysiological and physical factors involved in wound healing processes. The primary purpose of this study is to contribute a quantitative analysis of the effects of electrical current on wound tissue healing in SCI patients.

METHODS

Electrical stimulation was delivered from a dual channel stimulator. Tetanizing currents were applied through four electrodes across the wound. The frequency of biphasic current stimuli was 40 Hz and the pulse width 250 µs. The stimulation was 4s on and 4s off. The amplitude (up to 50 mA) was adjusted to achieve minimal muscle contraction when feasible. Stimulation was applied for 30 min daily. The volume of the wound was measured once weekly by measuring its surface and depth. Wound surface was approximated by an elipse. Additional data were obtained by photographing wound surface. The data of the surface were stored by means of digitizing tablet after projection of slides. CAD program was used for entering the shape and calculation of the skin area (Fig.1). For bacterial tests the wound tissue samples were taken once weekly from the center of the ulcer,the periphery, and from the eventual pockets.

Ten spinal cord injured patients with thirteen decubitus ulcers were included in the study. Seven of them with nine ulcers were treated by electrical stimulation. Three other patients with four ulcers were included in the control group. For four weeks the wounds were treated by conventional methods and controlled once weekly. After this period electrical stimulation was added to these patients as well. The patients have developed these wounds over several weeks (from 2 days to 86 weeks). Patients' data are presented in Table I.

RESULTS

The time-histories of stimulated wound areas are shown in Figs. 2 and 3 (Fig. 2B for sacral wounds and Fig. 3B for wounds over trochanter major). In order to improve clarity of presentation, the time courses are normalized with the corresponding initial wound area. Hence, the problem of different orders of magnitude of the initial wound area at the beginning of the observation is avoided. The results presented in this way indicate that the rate of healing can be approximated by the exponential function. In order to get insight into the actual values of time constants of the healing process the logarithm of actual wound area are plotted with respect to the time (smaller graphs). It is evident that they are rather close to the linear function. Therefore:

$$\ln\ y(t)/y_0(t_0) = -\frac{t}{T},$$

where:

$y(t)$ is the current value of wound area at time t;
$y_0(t_0)$ is the initial value of wound area at time t_0;
T is time constant of the healing process.

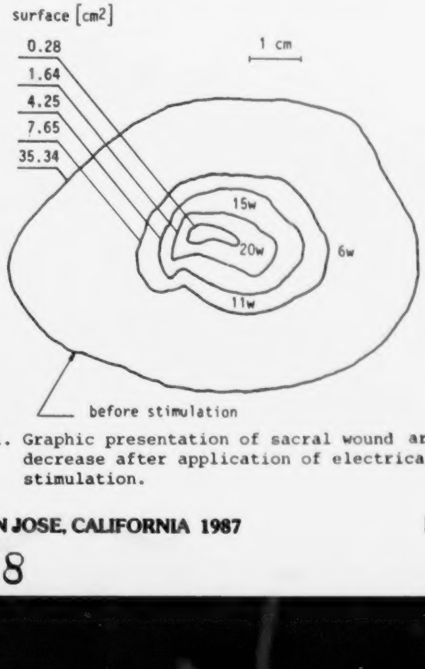

Fig.1. Graphic presentation of sacral wound area decrease after application of electrical stimulation.

TABLE I. DATA OF THE TREATED WOUNDS

Wound	Level of patient's SCI	Age	Duration of disability	Wound location	Duration of wound before treatment	Initial wound		Before electrical stimulat.	
						area /cm^2/	depth /mm/	area /cm^2/	depth /mm/
1.	S.D.,Th 1-3	31	6 w	sacrum	4 w	22.05	40	9.66	35
2.	H.Z.,C-6	29	7 m	sacrum	2 days	0.39	3	0.39	3
3.	- " -	-"-	-"-	right troch.major	-"-	3.82	-	0.39	-
4.	T.J.,Th-4	62	12 y	-"-	86 w	1.98	-	1.88	-
5.	T.G.,Th-10	17	10 w	sacrum	10 w	-	-	35.34	40
6.	B.M.,C6,7	57		-"-	16 w	-	-	6.68	5
7.	Č.Z.,Th7,8	48	4 m	-"-	16 w	-	-	18.84	10
8.	K.J.,Th6	35	90 m	-"-	4 w	-	-	1.88	-
9.	-"-	-"-	-"-	left troch.major	7 w	-	-	3.53	-
10.	A.K.,L4	29	5 m	-"-	19 w	-	-	6.48	-
11.	K.A.,L1	25	14 m	-"-	2 w	-	-	6.87	-
12.	R.E.,C6	22	2 m	-"-	6 w	-	-	15.71	-
13.	-"-	-"-	-"-	right troch.major	-"-	-	-	56.55	3

The estimated values of the time constant are 4.7±0.9 weeks for sacral wounds and 2.4±0.4 for trochanter wounds. Up to the present, a lack of data regarding time hystories of wound treated by classical treatment has not allowed estimation of time constants with statistical significance. Time plots corresponding to the initial values less than 1 cm^2 are not considered due to relative high measurement errors.

Bacterial analyses showed in some wounds (either control or treated) the presence of following bacteria: acinetobacter calcoaceticus, staphylococcus aureus and proteus mirabilis. No correlation was found between the rate of healing and the type of bacteria.

DISCUSSION

During the work it became clear that consistent evaluation of the results requires not only careful distinction between patient's population, but also between the location of observed wounds. The wound areas over trochanter major decrease almost twice as rapid as sacral wounds. Certainly, the depth of sacral wounds diminishes the rate of decrease, presented by the changes in area of wound surface. However, it can be assumed that the variety of tissue consistence in different wound location inply the different healing rates. It was shown that the healing process has an exponential behaviour. Present studies (2,6) (mostly qualitative) do not report the time-histories of healing process. However, Wheeler and co-workers (3) asserted that electrical stimulation during the first few weeks of application acts as a "trigger" for reparative processes. They also reported that electrical stimulation with cathodal currents produces antibacterial effects (3). Our results do not support this observation. Also, Edel and Freund (4) did not show any correlation between the changes in bacterial type and healing process in spite of using cathodal currents. The discrepancy might be explained by the different stimulation regimens used up to the present (cathodal DC currents and biphasic AC currents), and in the complexity of physiological mechanisms affected by the treatment.

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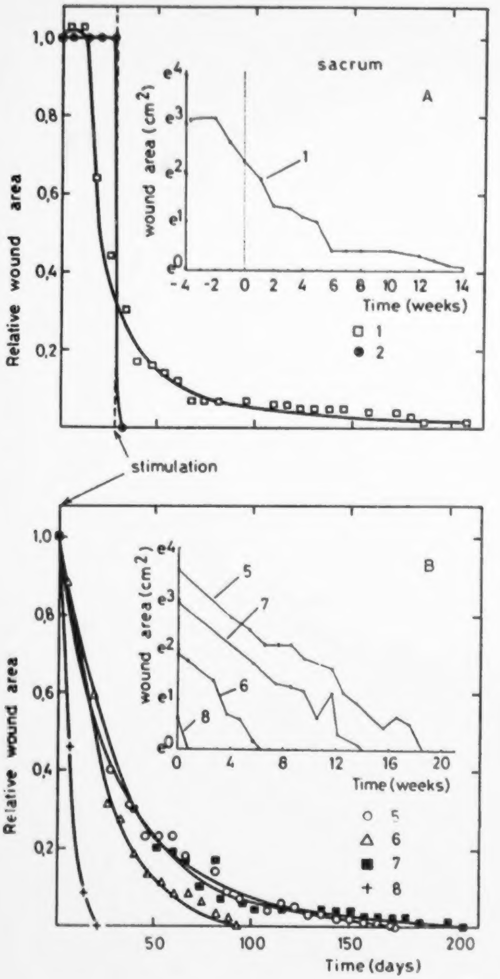

Fig.2. Time histories of the sacral wound areas normalized by the initial wound area. A - control wounds. Dashed line signifies the beginning of application of electrical stimulation. B - Wounds treated by electrical stimulation. Smaller graphs represent the logarithmic values of absolute wound areas.

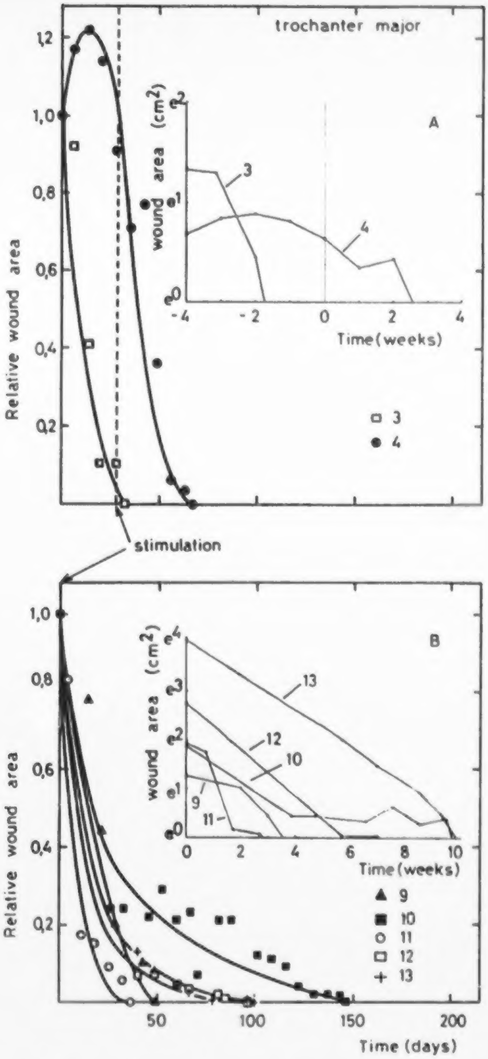

Fig.3. Time-histories of the throchanter wound surfaces. For additional comment see Fig.2.

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PARAPLEGIC SUBJECTS' EXPERIENCE IN AN FNS RESEARCH PROGRAM

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ABSTRACT

Six healthy paraplegic subjects, ages 18 to 40, are participants in a research program designed to restore walking and functional tasks in paralyzed individuals (1). The program involves intramuscular implantation of electrodes in the lower limbs, hips and trunk. These electrodes are connected to a microprocessor-controlled muscle stimulator. When the stimulator is properly programmed and when a full set of electrodes is functioning properly, subjects are able to walk up to 800 feet and to ascend and descend stairs. Participation in this program is very challenging physically and emotionally, requiring a great deal of dedication on the prt of the subjects who give up considerable work or school time in order to progress. Despite the physical and emotional demands made on the participants, subjects feel that their involvement will be of great benefit, not only to themselves but potentially to thousands of other paralyzed individuals.

INTRODUCTION

Spinal cord injury is one of the most devastating injuries that can happen to anyone. Despite treatment by bracing and therapy, ambulation is achieved by only 25% of this population (2). It is felt that a new treatment approach, functional neuromuscular stimulation (FNS) may provide a better solution to the ambulation problem. At the Cleveland Veterans' Administration Medical Center, researchers are utilizing FNS, developing technological innovations, and applying them on paraplegic spinal cord injured subjects.

Participating as a research subject in the FNS program is demanding physically and especially emotionally (3,4). Subjects in the FNS program feel that they are helping to develop this technology so that in the future it may be utilized to help others achieve additional recovery from an extremely disabling condition.

MATERIALS & METHODS

After being accepted into the research program, for the first two or three months subjects undergo electrical stimulation of their muscles for the purpose of strengthening. Next comes a two month period during which subjects progress to standing while their muscles are being stimulated. If all goes satisfactorily, subjects will next walk in parallel bars (Fig.1), then with the aid of a walker (Fig.2), them with crutches (Fig.3). It generally takes about three more months until walker-level ambulation is achieved. A great deal more time is needed in order to acquire necessary balance and coordination before walking with the use of crutches is possible. After ambulation is achieved, programming and reprogramming are required to maintain and improve the quality of walking.

During the strengthening and standing periods subjects endure weekly 2-hour sessions during which electrodes are implanted at four sites in their lower extremities. Active subjects in the FNS project are required to spend 15 to 20 hours each week receiving electrode implants, participating in experiments, testing, FNS exercises and FNS functional tasks, including walking.

Eight paraplegic subjects underwent FNS ranging from standing to walking and climbing stairs. Details regarding each subject are listed in Table 1. All subjects had complete spinal cord injuries except for J.B.

RESULTS

Subjects reported noticing considerable muscle strengthening and development as a result of FNS. One of the benefits they reported was that as a result of this program their legs appeared more normal. More importantly, the heretofore lost abilities to stand and walk were, in part, regained and this increased the self-esteem of most of the subjects. There was no recorded damage to muscle, nor any joint abnormality as a result of FNS. However, subjects have expressed some concern for the integrity of their knee joints so arthroscopy has been scheduled for the near future. Two foot fractures were reported in the almost five year existence of the program. Aerobic studies showed improvement in cardio-vascular fitness of the subjects (5).

FIGURE 1: SUBJECT B.K., 1983

Bone density showed significant improvement versus other paraplegics who did not use FNS (6). Although no problems with decubitus ulcers due to implantation of electrodes has been seen, there is a minor problem with infections even though subjects keep their implantation sites clean with alcohol and cover them with a dressing. A problem with electrodes constantly moving and breaking in the first two weeks, requiring further implantation causes considerable stress, anxiety, and disappointment for all subjects.

Data were obtained from some of the subjects participating in the FNS project in an attempt to assess psychological effects of participation. They were asked to rate several variables on a scale from one to ten, in order to get a subjective measure of satisfaction with the program. Other variables were rated only positive, negative or no effect.

Subjects were asked "How important is your participation in the FNS project with regard to:

	R.L.	A.B.	D.J.	B.K	D.C
Pride in doing it for others	5	6	7	8	5
Personal physical accomplishment	5	4	8	6	5
Effect of failures	7	8	5	8	9
Education	0	+	+	+	0
Job	0	0	+	-	-
Emotional involvement	-	+	+	+	+
Attitude toward project	vary	vary	vary	vary	+

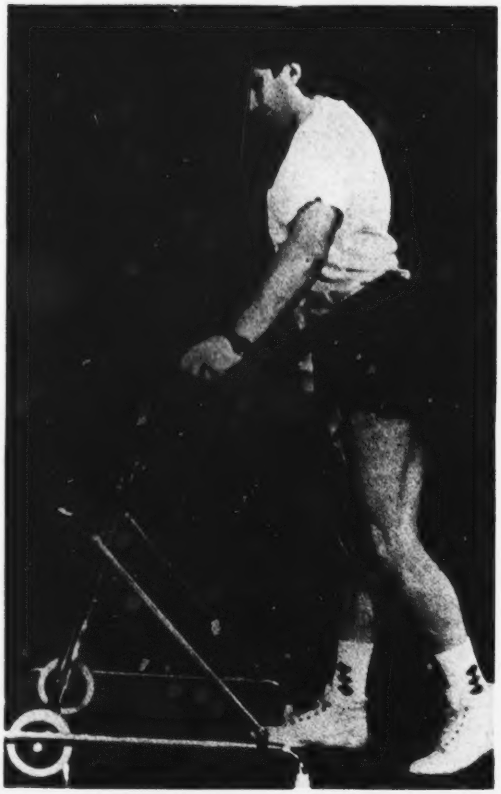

FIGURE 2: SUBJECT B.K., 1985

DISCUSSION

FNS subjects demonstrated that it is possible for complete paraplegics to achieve walking by using implanted percutaneous electrodes (Figs. 1, 2, 3). In addition to physical gains, very positive psychological effects have also been noted; mainly an increase in self esteem and pride in taking part in such an innovative, ground-breaking project.

Attitudes and psychological effect of participation can be seen to be quite variable. Several subjects report a negative effect on emotional involvement, education and job. Variable attitudes toward the project as a whole tend to reflect how well any one subject is doing on a given day or over a given period of time. The stress, frustration and enormous time commitment can best be demonstrated by the fact that while there are always six active FNS subjects, six others have dropped out. Those who have dropped out reported that while they were still enthusiastic about the project, the time commitment and the fact that they were not personally benefitting from the program provoked their leaving.

Table 1.

SUBJECT	SEX	AGE	INJURY	LEVEL	TIME/FNS	OCCUPATION	FUNCTION/FNS
B.K.	M	28	MAR/82	T8/9 SHOT	8/82	ENGINEER	CRUTCHES/STAIRS
R.L.	M	40	JUN/79	T9 AUTO	2/84	PHYSICIAN	WALKER
D.J.	M	30	FEB/80	T11 FALL	7/83	TECHNICIAN	WALKER, STAIRS
D.C.	M	26	NOV/83	T7 AUTO	6/84	UNEMPLOYED	WALKER
A.B.	F	18	OCT/85	T5/6 AUTO	9/86	STUDENT	STANDING
S.W.(0)	M	26	DEC/78	T4/5 SHOT	5/83	STUDENT	WALKER
J.B.(*0)	M	26	FEB/85	T4/5 AUTO	6/86	TAXIDERMIST	CRUTCHES
M.D.(0)	M	27	AUG/77	T5 AUTO	1/83	TAX EVALUATOR	WALKER

* Incomplete
0 No longer in the FNS project

Clearly further work needs to be done to refine the system, to make it less bulky, aesthetically acceptable, and to reduce the metabolic energy cost of using the system.

When all these problems have been addressed there is tremendous hope for thousands of paralyzed people currently confined to wheelchairs, who will have less worry about barriers in their daily existence.

A number of subjects sacrifice some of their personal development (job, education) due to the time demands of the project. However, they continue in the hope that in the near future it will be a routine task to use FNS in daily life, and that their hard work and time will benefit not only themselves, but also others.

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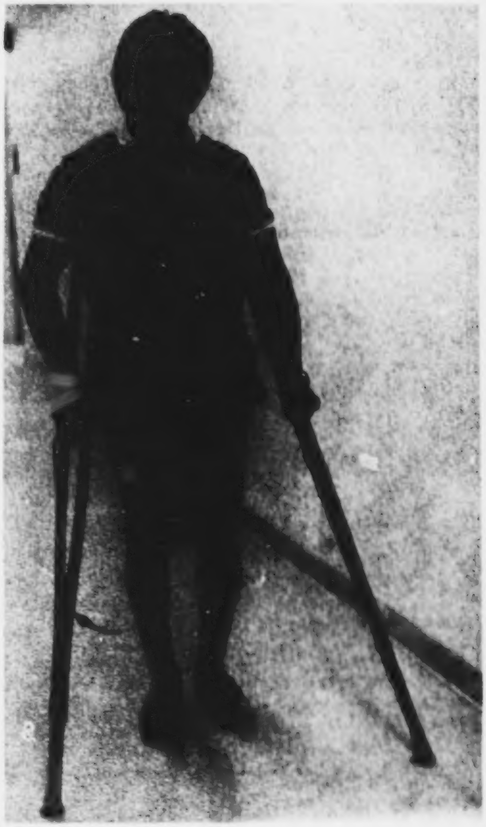

FIGURE 3: SUBJECT B.K., 1985

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HEMODYNAMIC RESPONSES DURING ELECTRICALLY-INDUCED LEG AND VOLUNTARY ARM CRANK EXERCISE IN LOWER-LIMB DISABLED MALES

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ABSTRACT

Twelve paraplegic males performed submaximal arm crank exercise (ACE) alone, and during concurrent functional neuromuscular stimulation (FNS) of paralyzed leg muscles to determine the individual and combined (HYBRID) effects upon central hemodynamic responses. FNS exercise consisted of rhythmic asynchronous static contractions of hamstrings, quadriceps, gastrocnemius and tibialis anterior. Oxygen uptakes during ACE were not appreciably different from the HYBRID condition, suggesting that the contribution of FNS-induced muscle contractions to whole body exercise metabolism was negligible. However, subjects responding vigorously to FNS displayed 10-19% higher ventricular stroke volumes matching 6-19 b·min^{-1} lower heart rates under conditions of HYBRID exertion compared to ACE alone. Resting and exercise cardiac outputs were also augmented by 7-39% during FNS. In contrast, no alterations of circulatory hemodynamics were observed in non-FNS responsive Control subjects undergoing similar electrical stimulation exercise. These data support the view that lower-limb FNS augments central hemodynamic responses during upper body exercise, and may also attenuate circulatory hypokinesis resulting from lower-limb blood pooling in paraplegics.

INTRODUCTION

In the healthy, upright human, venous return to the heart during lower-limb exercise may be aided by; a) the cyclic respiratory variations of intrathoracic and intra-abdominal pressures (the "respiratory pump"), b) the dynamic effect of muscular contractions during leg movement (the "muscle pump"), and, c) sympathetic vasoconstriction of the postcapillary capacitance vessels. In paraplegic individuals, one or more of these physiologic responses may be compromised as a result of spinal cord trauma. Thus, a significant factor affecting both the central and peripheral adaptive responses to arm work is the extent to which blood pooling in the buttocks and lower limbs of spinal cord injured (SCI) subjects limits their exercise tolerance. Tilt-table studies (1,2) and lower-body positive pressure trials (3) have confirmed the poor peripheral vascular control and reduced venous return in those lacking sympathetic venomotor tone.

Functional neuromuscular stimulation (FNS) has been previously used in an attempt to recondition weak or paralyzed muscles (4,5), enhance cardiorespiratory fitness via FNS-induced bicycle ergometry (6,7) and control gross motor skills such as upright ambulation (8). However, there has been little research evaluating the efficacy of FNS exercise to reverse circulatory hypokinesis in paraplegics with a view to improving their upper-body exercise capacity. It is not yet clear if cardiac output, peripheral blood flows, and, especially venous pooling are substantially altered by such exercise. Data on central and peripheral hemodynamic responses to FNS exertion, as well as plasma concentraions of catecholamines and other stress hormones are needed to complete the picture of cardiovascular control in SCI individuals undergoing combined (HYBRID) voluntary upper-body and FNS-induced leg exercise. The purpose of the present investigation was to examine the effects of concurrent FNS-induced lower limb exercise during arm crank ergometry upon central (ie. cardiac output, stroke volume, heart rate) and peripheral (arteriovenous oxygen extraction, blood pressure, total peripheral resistance) hemodynamic responses.

METHODS

Twelve asymptomatic men (age = 26.1 ± 5.3 yr, $\dot{V}O_2$peak = 2.01 ± 0.40 l·min^{-1}), significantly disabled by neuromuscular deficits but otherwise healthy, were recruited for the present study. After routine medical examination and completion of informed consent, physical characteristics were determined by standard laboratory procedures. Submaximal and maximal exercise assessments were conducted separately, 24 h to 7 d apart, at the same time of day. Subjects operated a modified Monark ergometer at 60 rev·min^{-1} while oxygen uptake ($\dot{V}O_2$), heart rate (HR) and expired ventilation ($\dot{V}_E$) were determined using open circuit spirometry. Maximum power output and $\dot{V}O_2$peak were assessed during a progressive test (1 minute stages of 8.6 W) to volitional fatigue. Submaximal cardiac output ($\dot{Q}$), stroke volume (SV), systolic time intervals and indices of myocardial performance were estimated using impedance cardiography immediately following 6-7 min of steady-state arm crank exercise (ACE). Arteriovenous oxygen extraction (a-$\bar{v}$ O_2 diff) was calculated from $\dot{V}O_2$ and $\dot{Q}$. Total peripheral resistance (TPR) was estimated from cardiac output and ausculated blood pressures recorded immediately post-exercise. All measurements were performed at rest, 30 W ACE and 60 W ACE. Fingertip blood lactate samples were drawn during the recovery periods approximately 2 min after each submaximal exercise bout.

Following 1-3 weeks of FNS habituation, the subjects performed two exercise trials in randomized order comprising; a) ACE alone, or, b) ACE with concurrent static muscle contractions (HYBRID). HYBRID exercise encompassed rhythmic, asynchronous, isometric contractions of hamstrings, quadriceps, gastrocnemius and tibialis anterior. An 8-channel electrical stimulator (4 muscle groups on each leg) provided the asynchronous pattern of thigh-calf static contractions. Stimulation characteristics consisted of biphasic pulses of 300 microsecond width at 35 Hz, delivered through surface electrodes over the neuromuscular motor points (9,10). A duty cycle of 1.5 s (ie. 1.5 s on and 1.5 s off) was employed to ensure a significant neuromuscular activation. Six men exhibiting vigorous contractions were classed as 'responders' (R) to FNS, while the remaining subjects served as 'non-responder controls' (C).

The physical characteristics and maximal exercise data of R and C groups were compared using a one-way analysis of variance. A three-way analysis of covariance was utilized to assess differences between groups (R versus C), among conditions (ACE versus HYBRID) or across exercise levels (Rest, 30 W, 60 W). Differences of physical characteristics, maximal cardiorespiratory responses and submaximal hemodynamic data were considered significant at the 5% level.

RESULTS

The control (C) and responder (R) groups did not differ significantly with respect to age, physical characteristics or cardiorespiratory fitness level (Table 1).

Table 1. Physical Characteristics. Values are means ± SE.

	Responder Group (n=6)	Control Group (n=6)
Age, yr	25.3 ± 2.0	26.8 ± 2.5
Body height, cm	177.8 ± 2.3	181.5 ± 1.5
Body mass, kg	77.0 ± 3.8	76.4 ± 7.5
Surface Area, m^2	1.95 ± 0.1	1.96 ± 0.1
$\dot{V}O_2$peak, $l \cdot min^{-1}$	2.06 ± 0.2	1.95 ± 0.1
$ml \cdot kg^{-1} \cdot min^{-1}$	27.2 ± 3.2	27.2 ± 3.8
Resting HR, $b \cdot min^{-1}$	65.5 ± 3.9	72.0 ± 4.4

Oxygen uptakes at rest and during ACE were 0.27 ± 0.04 $l \cdot min^{-1}$ (Rest), 0.88 ± 0.07 $l \cdot min^{-1}$ (30 W) and 1.31 ± 0.06 $l \cdot min^{-1}$ (60 W), respectively, and these data were not appreciably altered under the HYBRID condition for either group.

The R group demonstrated a 10-19% augmentation of SV during HYBRID exercise compared to ACE alone (Figure 1). Although the C group also displayed a marginal increase of SV at rest and during ACE under conditions of FNS exercise, these data were not statistically significant.

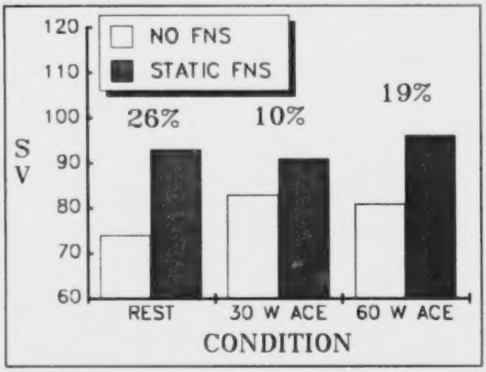

Figure 1. Stroke volume (SV) at rest and during arm cranking (ACE) in 'Responders' to functional neuromuscular stimulation (FNS). Values are means ± SE. Percentages refer to differences between conditions.

As increases of SV above non-FNS levels were coincident with decreased exercise HR (by 4-16 $b \cdot min^{-1}$ at 30 and 60 W), $\dot{Q}$ and TPR were only moderately enhanced in R subjects (Figure 2). Cardiac output and TPR remained unchanged during FNS at rest through 60 W ACE in the C group. Similarly, alterations of myocardial performance indices (eg. Heather Index and systolic time intervals) or peripheral venoarterial oxygen extractions ($a\text{-}\bar{v}\ O_2$ diff) were equivocal following FNS-induced muscular contractions during ACE in R and C subjects.

DISCUSSION

The small differences of $\dot{V}O_2$ between ACE and HYBRID exercise suggests that the contribution of electrically-induced leg movements to whole body metabolism is negligible. The marginal elevation of oxygen consumption during FNS-exercise generally supports our earlier research (10,11) which indicated that this modality is either too intermittent or inconsequential by itself to promote a cardiorespiratory training effect. In a concurrent investigation (12), ACE with simultaneous FNS-induced dynamic knee extensions produced a reduction of exercise blood lactate levels by 54% (at 30 W) and 48% (at 60 W) in R subjects, supporting the concept of improved lactate clearance during arm effort as a corollary of FNS-induced leg movements. No similar lactate metabolic effect was observed in the present study using static contractions; fingertip lactic acid concentrations were not significantly different under conditions of ACE versus HYDRID exercise.

A significant issue raised by several authors (2,13,14) has been the extent to which circulatory hypokinesis arising from peripheral venous pooling affects the exercise capacity of paraplegics. Previous studies (reviewed in 15) have noted 15-30% lower stroke volumes and 10-25% diminished cardiac outputs in tetraplegics or paraplegics performing comparable upper-body exercise as their able-bodied counterparts. Recently, Glaser (16) has speculated that FNS-induced leg exercise may prevent or reverse peripheral blood pooling, and thereby augment venous return to the heart. The 10-24% increase of SV during simultaneous FNS static contractions (Figure 1) at rest, 30 W and 60 W ACE had a positive effect upon myocardial performance by decreasing exercise HR and rate-pressure-product (an index of myocardial $\dot{V}O_2$). Interestingly, few alterations of circulatory hemodynamics have been observed coincident with ACE and dynamic knee extension exercise (described above; reference 12), raising questions as to its efficacy in reducing venous pooling compared to the present technique. Further research is warranted examining the central and peripheral hemodynamic effects of ACE+FNS(static) versus ACE+FNS(dynamic) HYBRID training modalities.

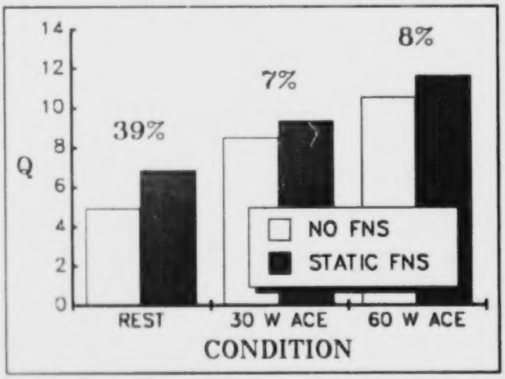

Figure 2. Cardiac output ($\dot{Q}$) at rest and during arm cranking (ACE) in 'Responders' to functional neuromuscular stimulation (FNS). Values are means ± SE. Percentages refer to differences between conditions.

Despite the marked increases of stroke volume from rest to exercise levels in the present study, cardiac output (Figure 2) was only moderately enhanced (by 7-8%; $p \geq .05$) in the R group under HYBRID conditions, suggesting that while physiologic stress may be lowered, exercise performance is not necessarily improved. In contrast, at rest $\dot{Q}$ was significantly augmented from 4.9 $l \cdot min^{-1}$ to 6.81 $l \cdot min^{-1}$ (an increase of 39%; $p \leq .05$). A similar pattern was observed for blood pressures and TPR; a small, non-significant improvement during arm cranking supporting a marginally reduced physiologic stress consequent upon isometric FNS contractions.

Davis and co-workers (17) noted that disabled subjects displaying an initial hypokinetic circulation, demonstrated a marked increase of $\dot{Q}$ and SV following upper-body conditioning regimens. These physiologic alterations could be brought about by an augmented myocardial contractility and/or reduced total peripheral resistance. In conclusion, our data support the view that static lower-limb FNS also enhances central hemodynamic responses during upper-body exercise, and may furthermore attenuate circulatory hypokinesis in paraplegics.

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VOLUNTARY STRENGTH GAINS IN PARETIC MUSCLE AFTER HYBRID (FNS-VOLUNTARY) EXERCISE TRAINING

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ABSTRACT

In paretic muscle, HYBRID exercise (voluntary contractions assisted by FNS) can result in greater force production than by either exercise modality alone. The purpose of this preliminary investigation was to examine the methodology and determine if HYBRID training would result in significant strength and/or range of motion increases in a population significantly weakened as a result of injury to the central nervous system. Four subjects (2M, 2F, mean age = 35 ± 5 yr) with incomplete SCI, head trauma or CVA resulting in reduced strength in the lower limbs were recruited for participation. Voluntary quadriceps strength (knee extension) was assessed pre- and post-training, at 6, 18, 30, 60, 120, 180 and 300 deg·s^{-1}. Training consisted of 3 sets of 10 knee extensions (each at 30 deg·s^{-1}) performed 3x·wk^{-1} for 8 weeks. Prior to each session, the maximum tolerable level (MTL) of FNS was determined by gradually increasing stimulation intensity across two surface electrodes. Training sessions consisted of maximal voluntary contractions of the quadriceps upon which MTL FNS was superimposed. This training resulted in greater mean voluntary force outputs and peak angles of knee extension following the training. It is suggested that training via this HYBRID method may be more beneficial for a disabled population than voluntary training alone.

INTRODUCTION

The uses of electrical stimulation alone, or in conjunction with voluntary exercise has been examined extensively in a healthy population (3,4,6,9,12,13,14,17). Moreover, functional neuromuscular stimulation (FNS) has also been used for inducing contractions in paralyzed or weakened muscle groups (5,7,8,11). In a disabled population, combinations of FNS-induced and voluntary exercise (HYBRID) of paretic muscles can result in greater force production than by either modality alone (15). While several authors have demonstrated the value of FNS training in the rehabilitation process after knee injury (5,11), there has been very little examination of the possible benefits of this technique in a population significantly weakened by chronic conditions such as incomplete spinal cord injury, head trauma or cerebrovascular accident. In a review by Baker (1), some of the values and limitations of clinical electrical stimulation for patients with CNS disorders was explored.

Skeletal muscle strengthening has traditionally been accomplished by progressive resistance exercise. Most protocols incorporate either isometric or isotonic contractions. When FNS is applied, it has generally been in an isometric mode (3-6, 11-13). Strengthening the muscle isotonically usually involves systems of free weights, or weight lifting devices. One drawback to these training methods is that the most weight which can be lifted is that amount allowed at the weakest point in the range of motion (ROM).

More recently, devices such as the isokinetic dynamometer have permitted dynamic contractions to be performed at maximal intensity throughout the entire voluntary ROM. In a population with some physical limitation, this mode of exercise, especially for testing, can be extremely beneficial (18). Isokinetic exercise allows the patient to perform maximal contractions even at joint angles where contractions are extremely weak. Watkins (18) quantified muscle performance isokinetically in patients with neurological disorders and found significant deficits in peak torque when compared to a matched group of healthy able-bodied individuals. We have previously demostrated that peak torque could be significantly increased by superimposing neuromuscular stimulation upon a maximal voluntary isokinetic contraction of a paretic muscle group (15), while there was little or no effect on maximal contraction of able-bodied individuals (16). HYBRID exercise, which leads to increased force output should also increase training capability. An increase in the the strength of the muscle may increase voluntary force output since the intact motor pathways would then be controlling stronger muscle.

PURPOSE

The purpose of this preliminary investigation was to examine the methodology and determine if training using the HYBRID mode would result in significant strength and/or ROM increases in a population significantly weakened as a result of injury to the central nervous system. Voluntary quadriceps strength (peak force in Nm), and peak extension angles were determined before and after 8 weeks of HYBRID training, which consisted of voluntary effort combined with electrical stimulation exercise.

SUBJECTS

Four disabled subjects (2 male, 2 female; mean age = 35 ± 5 years) volunteered to participate in this study. Subjects had incomplete spinal cord injury, head trauma or cerebrovascular accident resulting in significant motor paresis as demonstrated by less than normal voluntary strength in their lower limbs. The average voluntary peak torque for this group, at a velocity of 30 deg·s^{-1}, was only 61.6 Nm and these data are consistent with the findings of Watkins (18). In contrast, healthy, able-bodied individuals would exhibit well over 100 Nm at that same isokinetic velocity (2,18). Subjects' characteristics are listed in Table 1.

Table 1. Subjects' age and disability characteristics

SUBJECT I.D.	INJURY	AGE	TIME SINCE INJURY
M 1	Hd. Trauma	21	13 months
F 1	Inc. SCI	33	12 months
M 2	Inc. SCI	40	11 months
F 2	CVA	45	24 months

All subjects were informed of inherent benefits and risks of participation in the training program, and each signed a statement of informed consent in accordance with the guidelines of the IRB of Wright State University.

METHODS

The dynamic strength and peak angles of extension of the quadriceps muscle group in both legs was determined by having the subjects perform knee extension exercise while seated at a Cybex II isokinetic dynamometer. Strength and extension measurements were recorded (dual-channel strip chart recorder) at joint-specific velocities of 6, 18, 30, 60, 120, 180 and 300 $deg \cdot s^{-1}$ and all torques were corrected for gravity according to the methods described by the Cybex Corporation (10). Exercise training was performed on a Cybex Orthotron isokinetic device. The training protocol consisted of 3 sets of 10 repetitions knee extension exercise, performed 3 times per week for 8 weeks. These contractions were all performed at 30 $deg \cdot s^{-1}$ for approximately 3 sec. Knee extensions were begun with the knee in 90 deg of flexion where full extension would be an angle of 180 deg. Immediately upon return to the resting position (90 deg), the next contraction was initiated. There was a 2 minute rest period between sets. Training simulated the testing procedure used for pre- and post-tests.

Prior to each exercise training session, the maximum tolerable level (MTL) of electrical stimulation was determined. Intensity across two surface electrodes (one common, placed proximal to the patella; and one active, placed over the best responding quadriceps motor point) was gradually increased until the subject indicated his or her highest tolerable level. Stimulation (square wave pulses, 300 usec duration, 35 Hz) was always high enough to initiate visible quadriceps contraction but never so high as to be painful. Each training repetition consisted of a maximal voluntary contraction of the quadriceps upon which MTL FNS was superimposed. This was accomplished by having the technician indicate a start time for each contraction to the subject while, simultaneously, applying the FNS. In a pilot study, these HYBRID contractions were found to generate more torque than voluntary contractions alone (15). This is represented in Figure 1.

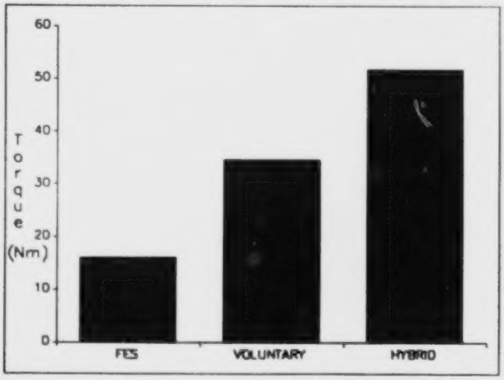

Figure 1. Peak torque generated under three conditions at 30 $deg \cdot s^{-1}$.

RESULTS

Changes in voluntary peak torque produced at each of the tested speeds (pre- to post-tests) are indicated in Figure 2. There was an increase in the group's average peak torque produced voluntarily, and it was evident at all speeds tested. Increases ranged from 7.3 Nm to 20.1 Nm (Nm = 1.356·Ft-lb), with the largest increases coming at the mid-range velocities.

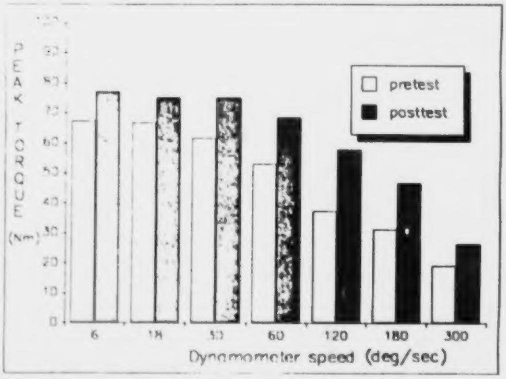

Figure 2. Group mean voluntary peak torque production (pre- and post- training) at each of the tested speeds.

Changes in the voluntary peak angle of extension, indicative of ROM, are evident in Figure 3. Following the training period, there was an obvious increase in the ROM at the faster speeds of 120, 180 and 300 $deg \cdot s^{-1}$ as the subjects could voluntarily extend to greater angles by 16, 12, and 30 degrees, respectively.

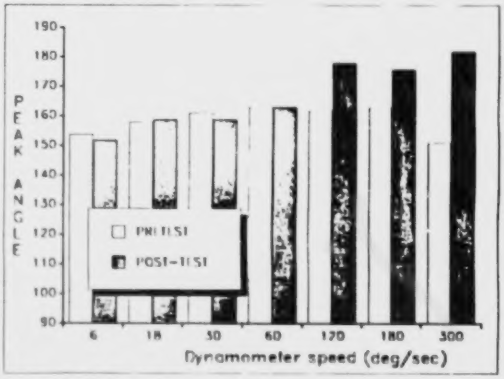

Figure 3. Peak voluntary extension angles pre- and post-training.

DISCUSSION

It has previously been established that FNS can be effective as an exercise regimen, but appears to have been most often employed for static contractions. For able-bodied individuals, applying electrical stimulation to a maximal voluntary contraction has been relatively ineffective (16). However, it has been used with limited success in a clinical population (5, 11). For dynamic exercise, where muscle response varies through the ROM, there has been little examination of the clinical value of FNS. Therefore, in this study, FNS was superimposed on maximal dynamic contractions of subjects who were decidedly weak. The method used was effective but variable in its application. The technician would push an activation switch on the stimulator at virtually the same time that the subject would begin the contraction. Even though this worked well, we are currently examining a system which is automated and would have the stimulation applied immediately upon initiation of the subject's contraction.

Previously, we demonstrated that this type of HYBRID exercise could augment the amount of torque produced in a weakened population (15). The present study indicates that it also precipitates a training effect when applied in a structured protocol over time. The increases of peak torque produced at all isokinetic speeds is interesting since training was performed only at one, relatively slow ($30\ \mathrm{deg \cdot s^{-1}}$) speed. Generally, training at slow speeds has the effect of increasing peak torque at slow speeds but not at fast (2). This present group of subjects could voluntarily generate only minimal torque at fast speeds before training, and were comfortable with $30\ \mathrm{deg \cdot s^{-1}}$. The increase in strength at all speeds was probably a function of the subjects being so weak initially that the training in general had a positive effect on all their activities. Stronger muscle, and thereby a stronger contraction, is also a reasonable explanation for the increases in ROM. Even if the neural patterns remained the same, innervation of the stronger muscle should have resulted in these positive responses. It is also possible that there was an increase in the subjects' flexibility and functional ability during the 8 week training period which might, in part, account for the increases in extension angles.

CONCLUSIONS

This study was designed to examine the question of using FNS as an adjunct to a standard voluntary training program in muscles which are weakened by neuromuscular deficits. It appears that a significant strength training effect could be achieved via this type of HYBRID exercise. Further research is indicated which should include: 1) a larger sample size, 2) a group who train without FNS, and 3) a non-exercise control group.

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AN ELECTRICAL STIMULATOR FOR FUNCTIONAL NEUROMUSCULAR STIMULATION EXERCISE

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ABSTRACT

Functional neuromuscular stimulation (FNS) exercise may provide several important health and fitness benefits for patients with paralysis arising from neuromuscular impairments. The purpose of this project was to design and construct a portable electrical stimulator which could be used to induce FNS exercise in paralyzed muscles. This stimulator provides smooth, gradual control because of its ramped output, and can deliver adequate power to drive afflicted muscles at relatively high contraction forces via skin surface electrodes. It can be operated by the user since several important safety features have been incorporated. Output consists of DC pulses (e.g. 300 microsecond pulse-width at a frequency of 35 Hz) which are typically limited to 150 volts at 150 milliamperes. Electronic circuitry is comprised of three integrated circuits and four transistors which can operate on battery power for extended periods of time due to its low current drain. All of the components are readily available and inexpensive. This stimulator has been successfully used for research with disabled subjects participating in FNS exercise training programs.

INTRODUCTION

Recently, there has been increased interest in functional neuromuscular stimulation (FNS) research where muscles paralyzed by spinal cord injury (SCI) are exercised in an attempt to improve patient health, physical fitness, and rehabilitation outcome (1,2,4-7,9). Effective training protocols typically consist of repetitive limb movements through a predetermined range of motion, while the muscles are loaded with an appropriate resistance. Unfortunately, most portable electrical stimulators that are commercially available for subject use do not provide the smooth, gradual control of the muscles for this type of exercise. In addition, many do not deliver adequate power output to induce the forceful contractions necessary for effective muscle strengthening. Most laboratory constructed electrical stimulators that have been described in the literature appear too complex to be user operated, and they can not be readily used with conventional exercise equipment (3,5,8).

It is clear that any beneficial effects that may be derived from FNS exercise training will be lost after several weeks of detraining. Therefore, FNS exercise needs to become part of the lifestyle of SCI individuals if any gains in health and physical fitness are to be maintained. For this to occur, there is a need for: electrical stimulator systems that are safe, effective and easy to use; exercise equipment that can be used in conjunction with FNS to provide appropriate muscle loading; and, exercise protocols that are safe, effective and easy to follow. It was the purpose of this project to design and construct a portable open loop electrical stimulator that can be used to induce FNS exercise in paralyzed muscles. This stimulator: is relatively easy to use; can be user operated; provides for smooth, gradual contractions; delivers sufficient power to induce forceful contractions in subjects who respond to FNS; incorporates several important safety features; and is relatively inexpensive.

METHODS

The schematic diagram of the electrical stimulator is given in Figure 1. Solid state components include an LM324 quad operational amplifier (U1), a CMOS 4066 quad bilateral switch (U2), a CMOS 4011 quad 2-input NAND gate (U3), two NPN drive transistors (NTE-287), and complementary NPN-PNP output transistors (NTE-396, NTE-397). Two 9-volt batteries power the drive circuitry, whereas three series connected 67.5-volt batteries provide the high voltage output to the skin surface electrodes (Medtronic). Current drain is about 1-milliampere for the low voltage batteries, and from zero to 3-milliamperes for the high voltage batteries (depending upon the stimulator output level).

Clock Circuitry

U1A is configured as a square wave oscillator clock whose output pulses are typically set for a width of 300 microseconds, and a frequency of 35 Hz. Potentiometers R1 and R2 are used for precise adjustment of pulse-width and frequency, respectively. Clock output pulses trigger the control pin of solid state switch (U2B). This converts the incoming DC stimulator drive voltage from a continuous to a pulsatile signal for switching the stimulator output transistors.

Stimulator Drive Circuitry

In the quiescent state, momentary switch S2 (SPDT) is contacting negative voltage from potentiometer R3. This keeps the ramp integrator U1B output at full positive, which holds the output of comparator U1C at full negative. Since U1C triggers the control pin of solid state switch U2A, this switch is prevented from conducting, and no stimulator drive voltage is permitted to reach the output transistors. When S2 is depressed, it contacts positive voltage from potentiometer R4. This causes U1B output to gradually ramp toward negative, which immediately toggles the output of U1C positive, and permits U2A to conduct.

Amplifier U1D is also driven by integrator U1B, and its output ramps in the positive direction. This voltage is used to drive transistors Q1 and Q2 for stimulator output. Potentiometer R7 is adjusted to limit the output voltage (and current) to the desired level. The offset voltage of U1D is adjustable by potentiometer R5, and the range is limited by R6. The purpose of this offset is to have the stimulator output turn on and off at the threshold level of the muscle. R5 is adjusted while depressing momentary switch S1, which causes U1C output to go positive and permits stimulator output to occur. The ramp rate potentiometers (R3 and R4) are adjusted during actual subject use to control the velocity of limb movement (R4 for the up ramp, and R3 for the down ramp).

Stimulator Output Circuitry

High voltage transistors Q1 and Q2 are linear amplifiers that are driven by the output of U1D after the continuous DC signal is converted to pulses by the clock (U1A) and switch U2B. The collector of Q2 is connected to one of the skin surface electrodes (cathode). As Q2 conducts, this electrode comes closer to ground potential (negative high voltage). High voltage transistors Q3 and Q4 are

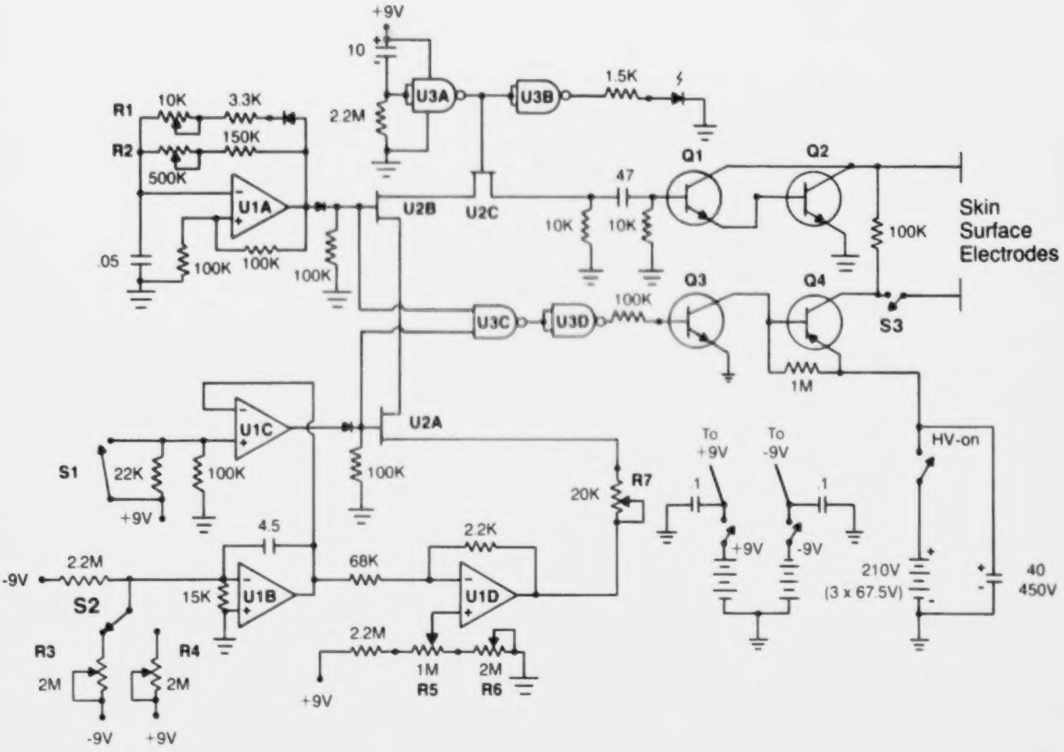

Figure 1. Schematic diagram of the portable electrical stimulator for functional neuromuscular stimulation exercise (capacitor values are in microfarads; diodes are Type IN914)

used to switch the other electrode (anode). The collector of Q4 is connected to this electrode, whereas the emitter is connected to the positive high voltage. Thus, when Q4 switches on, its electrode is essentially connected to the positive high voltage supply. This completes the stimulation circuit, and there is a current flow through the tissues which can induce muscle contractions. Control of Q3 and Q4 switching is accomplished by NAND gates U3C and U3D. Since the outputs of the clock (U1A) and comparator (U1C) are fed into U3C inputs, Q3 and Q4 are switched on only when S2 is depressed and U1C output becomes positive, simultaneous with the arrival of positive clock pulses.

Safety Considerations
[A] When power to the stimulator is first switched on, any possible stimulator output which could jolt the subject is eliminated by opening the drive line to Q1 and Q2 by having solid state switch U2C remain in the non-conducting state for approximately 20 seconds. This is accomplished by the RC time constant at the inputs of NAND gate U3A. NAND gate U3B activates a light emitting diode during this time to indicate that stimulator output is deactivated. [B] Because of the complementary transistor output configuration of Q2 and Q4 for duel electrode switching, possible short circuits in either transistor will not result in constant DC current flow through the tissues which could cause burns. [C] The maximal output of the stimulator is set by R7 to avoid hazardous stimulation levels. [D] The range of threshold level stimulation (R5) is limited by R6 to provide for smooth, easy adjustment, and to avoid hazardous output levels. [E] The stimulation output ramp is fully adjustable during the concentric (by R4) and eccentric (by R3) contractions. This helps avoid abrupt, jerky contractions which could damage deteriorated limbs. [F] Toggle switch S3 can be thrown by the subject if there is a desire to immediately stop all stimulation.

RESULTS AND DISCUSSION

Figure 2 illustrates this electrical stimulator being used during FNS knee extension exercise which is induced by stimulation of the quadriceps muscles. During contractions, the ankle pushes against a padded bar which raises a lever upon which load weights are supported. A progressive resistance exercise protocol that can be used had been previously described (5). This weight lifting system was designed to be used while the subject sits in his or her own wheelchair, possibly in the home environment.

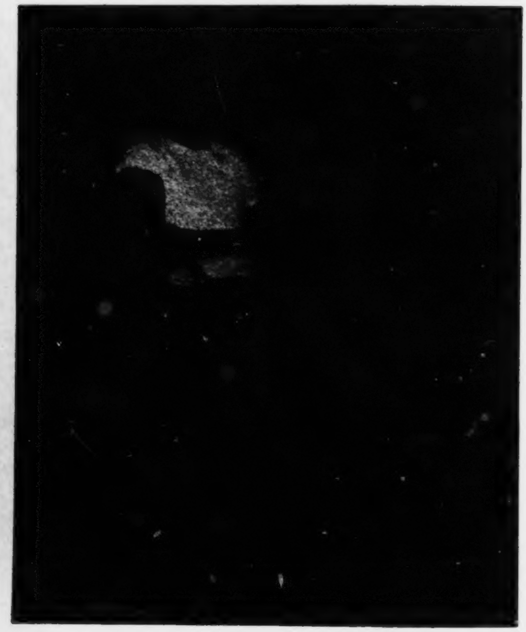

Figure 2. Illustration of the portable electrical stimulator to induce knee extension weight-lifting exercise. (Subject shown is not disabled).

During operation, electrodes are applied over motor points of the muscle, and the threshold stimulation level is set by depressing S1 and adjusting R5. When S2 is depressed, stimulation comes on at the threshold level and gradually ramps upward (R4) in intensity which typically results in smooth raising of the limb. When the desired target angle is reached, S2 is released causing the stimulation intensity to gradually ramp downward (R3) which typically results in smooth lowering of the limb. When the limb returns to the rest position, threshold stimulation automatically shuts off.

Although we consider this stimulator to be relatively safe to use, there are of course still risks of limb (and other) injury for subjects performing this type of exercise. For instance, muscle spasms can cause loss of limb control and jerky movements. Chronic exercise training can possibly cause the muscles to become stronger than the bones and joints can withstand. In addition, some subjects exhibit autonomic dysreflexia which can result in hazardous hypertension during FNS exercise. Therefore, subjects need to be well educated as to known risks, and closely monitored to increase the safety of this mode of exercise.

In conclusion, the described electrical stimulator has been sucessfully used for FNS exercise research. It has produced effective results, and induced smooth, forceful contractions in some subjects where portable commercial stimulators were found to provide insufficient output for training. We have experienced no electrode burns or orthopedic damage to any of our subjects.

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THE FEASIBILITY OF USING STRAIN MEASUREMENTS IN AN ANKLE-FOOT ORTHOSIS AS A FEEDBACK SIGNAL FOR CLOSED-LOOP FNS GAIT

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ABSTRACT

The use of strain measurements obtained from ankle-foot orthoses as feedback signals for closed-loop functional electrical stimulation to provide locomotion for paraplegics is considered here. Our approach is to interpret strain measurements from the metal upright of an ankle-foot orthosis (AFO) as an indication of the forces acting on it, and hence the forces acting on the lower extremity. A free-body analysis was carried out to predict the relationship between brace measurements and forces on the leg-brace system. Experiments have been done to evaluate the theoretical predictions. Additional experiments are underway to investigate the quantitative and qualitative relationships between gait phenomena and the sensor measurements.

INTRODUCTION

For over a decade the technique of functional neuromuscular stimulation (FNS) has been used experimentally in hemiplegic and paraplegic individuals, for the purpose of restoring standing and gait. Although promising results have been obtained in a large number of laboratories, many technical issues need to be resolved before FNS systems for standing and ambulation will be ready for clinical use.

Most of the work in this field has been with open-loop stimulation patterns. Thus, a subject's muscles are electrically stimulated according to a set pattern that has been stored in the memory of a microcomputer. At the Motion Study Laboratory at the VA Hospital in Cleveland, mid-thoracic level spinal cord injury patients are implanted with percutaneous intramuscular electrodes. They undergo a training period so that they are able to stand and ambulate in the supervised laboratory environment with the assistance of either walkers or crutches.

Problems with the present open-loop FNS walking system include a high rate of muscular fatigue, short duration of walking, 'unnatural' walking appearance, inability to traverse various surfaces and slopes, and a high rate of physiological energy expenditure by the patients. In addition, good balance during functional tasks while standing, and momentum control and balance during gait have not been realizable with open-loop stimulation.

Therefore, much effort has been directed towards closed-loop control of FNS gait, where electronic sensors measure quantities which serve as feedback signals for computer-based closed-loop controllers. Better control of the system is possible when the computer makes corrections in the stimulation to the muscles based on sensor measurements.

The work reported here is part of an overall effort to model paraplegic gait in terms of discrete events based on the detection of measureable quantities. Since it is reasonable to assume that the neural excitation necessary to perform a given task depends on the forces and moments at the joints (1), an effort was made to determine the feasibility of gaining this 'proprioception' through strain measurements in ankle foot orthoses (AFO's).

BACKGROUND

Several investigators have instrumented AFO's for various reasons and in various ways (2, 3, 4, 5). In 1970, Lehmann (2) reported mountingd transducers "just below the calf band or shell to monitor the force produced between the leg and the brace" in order to measure a bending moment at the knee. Lehmann (3) measured "force interaction between the calf band and the leg" and reported that a negative force is indicative of a bending moment at the knee and a positive force indicates an extension moment. However, Lehmann (4) did not make any connection between knee moment and bending moment in the brace upright, when he instrumented the uprights with strain gages. Lee (5) used a different method to measure the force between the calf band and the subject's leg. His transducer was bi-directional, "measuring both forces 'pushing' to flex the knee, as well as the forces 'pulling' to extend the knee." Neither Lee nor Lehmann reported on experiments to verify that their respective brace measurements, in fact, indicate knee moment. Our purpose here is to determine if such brace measurements do measure the knee moment and if they are useful as feedback signals for FNS gait.

METHODS

We first did a static analysis to predict which physical parameters are quantified if a metal upright of an AFO is instrumented to measure bending moment in the saggital plane. We then constructed and instrumented a brace to do this. Experiments were performed on normals to evaluate the findings of the theoretical analysis. A brief summary of each of these tasks is given here.

Theoretical Basis for Brace Measurements:

In the following static analysis of the leg-brace system, the brace is modeled as being coupled to the leg in two places. It is rigidly attatched to the foot at the bottom, in the shoe. The attatchment at the cuff is modeled as a collar on a rod, which means that there are only reaction forces perpendicular to the rod. Therefore, the brace is assumed not to be able to support any forces parallel to the brace uprights. For simplicity and ease of presentation, the system is shown in figure 1 as totally perpendicular to the ground. We can easily compensate for the effects of angular deviations by transforming between coordinate systems. As is evident from the static analysis, none of the vertical (ie. parallel to the shank) reaction forces act on the brace, while the horizontal (ie. perpendicular to the shank) forces act on both the leg and the brace.

Following is a summary of the free-body analysis:

$$Me = Mb-Fbx(d-e). \qquad ......(1)$$
$$Mb = -Fbx(a). \qquad ......(2)$$
$$Me = -Fbx(a+d-e). \qquad ......(3)$$
$$Mk = -Fgx(a+d+c) -Fgy(p). \qquad ......(4)$$

Subtracting (1) from (4),

$$Mk= Me-Fgx(a+d+c)-Fgy(p)+Fbx(a+d-e) \qquad ....(5)$$

But,

$$Ma= -Ffx(a)-Fgy(p). \qquad ......(6)$$

Substituting (6) in (5),

$$Mk=Me+Ma-Ffx(d+c)-Fbx(c+e) \qquad ......(7)$$

In the above equations,
Me = measured bending moment in the brace,
Mb = moment at the brace joint,
Fbx = force on the brace joint perpendicular to the shank,
Mk = knee moment,
Fgx = ground reaction force perpendicular to the shank,
Fgy = ground reaction force parallel to the shank,
Ma = moment at the anatomical ankle joint,
a = distance from the bottom of the foot to the ankle,
d = distance from the joint to the top of the brace,
c = distance from the top of the brace to the knee,
e = distance form the top of the brace to the gages,
p= distance from the center of pressure to the ankle joint, along the bottom of the foot.

Equation number 7 relates the knee moment, Mk, to the sensor outputs, Me. From equation 3, it is possible to solve for Fbx. For a paraplegic subject, it is reasonable to assume that Ma is zero if there is no stimulation to the ankle musculature. If we knew the relationship between Ffx and Fbx, we would be able to get a good approximation of the knee moment itself. However, this relationship is not known. Therefore, the measured brace output, Me, does not by itself determine knee moment.

Experimental Evaluation:

A single-upright AFO was instrumented with strain gages under the cuff of the brace on the metal upright. The bridge and amplification circuitry was built onto the brace for convenience and to minimize noise in the leads. Figure 2 shows the response of the brace sensor to known moments in the saggital plane.

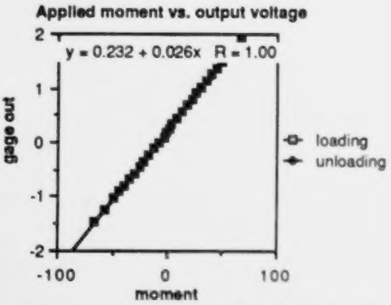

Figure 2. Results of testing with known moments in the saggital plane.

Stroboscopic experiments were conducted with a normal subject wearing the instrumented AFO, and data was recorded from force plates and footswitches. The subject took 7 steps on the force plates at a 'comfortable' cadence of approximately 50 strides per minute, and additionally simulated buckling of the knees while on the force plate. The analysis of the data consisted of direct calculation of the joint moments, and other computations pertinant to the equations derived for the brace output. In addition, multivariate regression techniques were employed to gain a better understanding of the interrelationships between the various parameters.

RESULTS

As shown in figure 3, the equation for the knee moment based on brace measurements quite accurately predicts the actual knee moment (R=.99). This verifies the theory advanced above to explain the output from the brace instrumentation. Therefore, it is possible to determine the knee moment from the brace measurements provided that other forces acting on the system are known or can be approximated. The brace measurements alone do a poor job of describing the knee moment (R=.55).

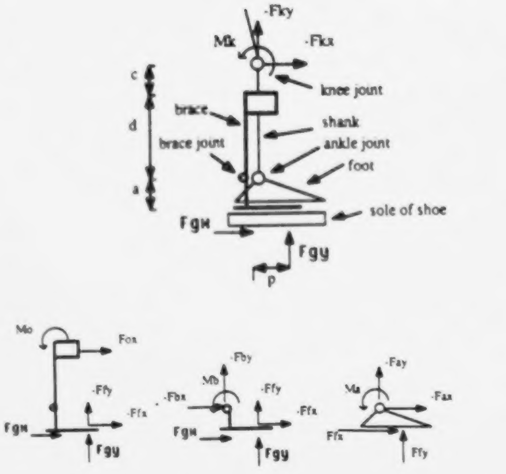

FIGURE 1. Model of the leg-brace system. The external forces acting on the system are shown above, and the internal forces are shown below

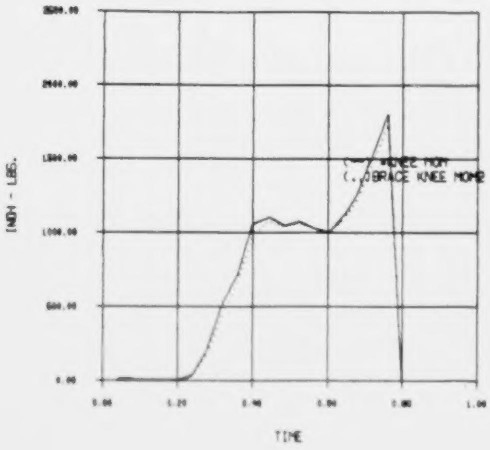

Figure 3. Knee moment calculated from strobe data (solid line) and from derived brace relationship (dotted line).

DISCUSSION AND CONCLUSIONS

The results reported here indicate that the measured bending moment in the upright of an AFO is not enough to determine knee moment. Both the static analysis and experiments demonstrate a relationship between the brace measurements and knee moment, but that other forces must be known for this relationship to be useful. Since it is impractical for us to rely upon force plates, efforts are currently underway to approximate these forces with 'portable' sensors. Further evaluation will have to be done to determine if the brace sensor, together with these force measurements will reliably determine the knee moment.

It is important to mention that our effort to measure the strain in the brace upright is part of a larger effort that requires reliable measurements of selected physical parameters. Even if the brace sensor cannot be used to measure the knee moment, it might be useful to us in other ways.

Future experiments to determine the usefulness of the brace measurements will include comparing the brace output to surface EMG's of the lower extremity. reaction forces, and other selected quantities. Paraplegic and normal subjects will be used in these experiments. From earlier experiments done with an AFO of slightly different construction we observed a relationship between the brace sensor output and surface EMG measurements. Also, using signal processing techniques, certain aspects of the signal (eg. critical points) can be selected for our purposes.

The prospects for using strain measurements in AFO's as feedback signals for closed-loop FNS gait seem to be good, but more work has to be done to determine its exact role in our application.

ACKNOWLEDGEMENTS

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USING STRETCH SENSORS TO MEASURE KNEE AND HIP ANGLES

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ABSTRACT

Capacitive stretch sensors are used to measure knee, hip and trunk angles. These sensors are small, light weight and, at present, externally mounted on the body. Initial evaluations indicate that angle measurements can be obtained when appropriate mounting and signal processing techniques are used. Further evaluation is needed to improve these techniques and ensure repeated accuracy of the angle measurements. These stretch sensors can be a valuable tool in the development and use of feedback controllers of posture and gait effected by Functional Neuromuscular Stimulation (FNS).

INTRODUCTION

Numerous methods exist for the measurement of knee and hip position in a laboratory environment. However recent investigations by several groups attempting to measure locomotion, gait, and balance outside of traditional gait laboratories have demonstrated the need for position sensing transducers that are portable, have repeatable performace, and are reliable under less than ideal conditions. For the development of closed-loop controllers that automatically adjust electrical stimulation to obtain functional motion from paralyzed muscle, feedback signal sources are needed that meet the above requirements and are also easy to mount and cosmetically acceptable (2,7,1).

Accurate measurements of joint angles (at the knee, hip and trunk) are important to the development and operation of systems providing paraplegic people with locomotion by means of functional electrical stimulation. In order to determine knee, hip and trunk position we are investigating the use of capacitive stretch sensors as an alternative to standard goniometers. Available goniometers which provide real time angle measurements have several drawbacks. These are often subject to slippage during walking and abrupt motion. The resulting errors and the consequent need for frequent recalibration complicate their use. Goniometers that are mounted at the knee or at the hip are often cumbersome and unsightly, restricting their use in clinical systems (4,6). This report describes preliminary results of experiments using stretch sensors to measure knee and hip/trunk angles in normal and paraplegic subjects, including methods of mounting sensors and techniques for processing sensor signals.

METHODS & RESULTS

Sensor Description

Our approach is to use sensors mounted on the skin, that can relate skin stretch to joint angle (5). In order to obtain accurate estimates of joint angles during standing or walking, multiple sensors and some form of signal processing are required. The sensor we are using is small and lightweight and can be mounted directly on the skin surface using Tegaderm, a stretchable medical adhesive patch. The sensor is a prototype of a future device that may eventually be implanted in human subjects. However, in the work described here only external mounting is considered.

The sensor operates by measuring changes in capacitance that are proportional to stretch induced displacements of the sensing element. The sensing element is a 13 mil stainless steel coiled wire encapsulated in silicon tubing; it can be of various lengths (8-16cm) depending upon its intended application. A CMOS hybrid circuit, enclosed in a 2.5cm x 1.75cm x .45cm flatpack converts the varying capacitance into a DC output voltage. The device weighs 9 grams.

Measurement of Knee Angle

To obtain measurements of knee angle using the capacitive stretch sensors, the flexible portion of the device should undergo a displacement of approximately 2.5 centimeters during the full range of joint motion (100 degrees of flexion). However the maximum sensor displacement must be limited to 3 centimeters to avoid damaging the device. It is essential that the entire length of the sensor remain securely fixed to the skin's surface, to ensure smooth and repeatable displacement of the sensing element during gait.

An appropiate mounting location for the sensor was obtained by trial and error. Sensors were mounted in various locations around the knee, and the amount of displacement for each location was recorded. The site chosen, location five on figure 1, limits errors introduced by muscle contractions and patellar motion, but is still sensitive to knee angle.

Angle measurements provided by the stretch sensors were compared to knee angle measurements made using a goniometer, and also to angles calculated from digitized strobe photographs. With careful mounting and calibration, the knee angles measured by the stretch sensor were similar to angles measured by the goniometer (Fig. 2). If the knee goniometer appeared to slip during a walking experiment, it was remounted and recalibrated. The goniometer and strobe data were used as a basis for comparison to the sensor angle measurements; however each of these standards is subject to measurement errors.

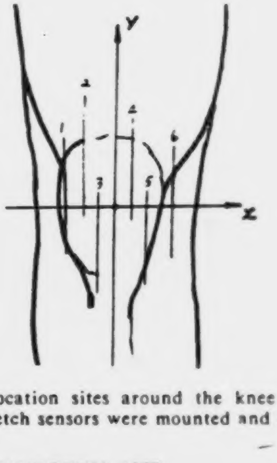

Figure 1. Location sites around the knee where the capacitive stretch sensors were mounted and tested.

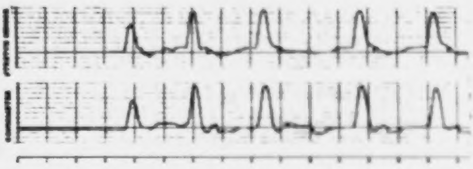

Figure 2. Knee angle measurements provided by a goniometer and a stretch sensor during paraplegic walking using FNS. Top trace - stretch sensor, Bottom trace - knee goniometer

Measurement of Hip and Trunk Angle

The capacitive stretch sensors were also mounted at the hip and trunk in order to measure angles in both the sagittal and coronal planes. The sensors were mounted in symmetric pairs about the mid-sagittal plane. Joint locations tested were: 1) on the lower back extending upward from just below the waist in line with the femurs; 2) on the frontal aspect of the pelvis just medial to the Anterior Superior Iliac Spine(ASIS); and 3) on the lateral aspect of the pelvis over the greater trochanters. As with the knee, we compared the stretch sensors' angle measurements with goniometer and strobe data. The sensor and goniometer outputs were sampled at 25Hz or 50Hz, and each input was buffered and low-pass filtered with a first order cutoff frequency of 12.5 Hz. In all experiments the sensors were calibrated to give a positive output voltage during hip flexion. Measurements of motion in the sagittal plane were obtained by averaging the two outputs of each symmetric pair of sensors. Measurements of motion in the coronal plane were obtained by taking the difference between the outputs of each sensor in the pair.

Results from one of the strobe experiments at the hip and trunk are given in Table 1. This data, supported by data from other experiments, indicates that more than one sensor is required for acceptable angle measurements. During experimentation two sources of error were identified and reduced. A noise component introduced into the sensor output signal by random fluctuation in skin stretch can be reduced by averaging the outputs from several (2 or 3) sensor pairs. Also, hysteresis effects caused by the skin and subcutaneous tissue can be suppressed by the inclusion of a derivative dependent term in the sensor output equation.

DISCUSSION

This evaluation of the capacitive stretch sensors shows that they may be a useful tool for obtaining measurements of joint angles. Accuracy and repeatabiltity of these measurements has not yet been statistically confirmed. Potential sources of error which are currently being investigated are the effects of muscle contraction, the impact of heel strike, and the effect of motion at an adjacent joint.

MEAN SQUARED ERROR			
plane of motion	1 pair	average 3 pairs	processed average
sagittal	28.31	21.63	7.74
coronal	80.23	42.17	10.01

Table 1. Mean squared error of stretch sensor angle data compared to strobe derived angle data for motion in the sagittal and coronal planes. The first column is the average of the errors obtained when one pair of sensors is used, the second is the error when the average of three pairs of sensor readings are used, and the third column is the resultant error obtained after processing the average with the addition of a derivative-dependent term.

ACKOWLEDGEMENTS

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QUADRICEPS MUSCLE RESPONSE TO FUNCTIONAL NEUROMUSCULAR STIMULATION DURING ISOKINETIC EXERCISE AND WALKING

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ABSTRACT

Clinical observations of three complete paraplegic subjects during walking with functional neuromuscular stimulation (FNS) revealed that one leg consistently buckled and/or fatigued before the other. Muscle torque data was collected with the Cybex dynamometer during FNS of the quadriceps muscles (vastus lateralis, vastus intermedius and vastus medialis) via percutaneous intramuscular electrodes (20 mA, 150 μs pulse width and 25 pps) to determine the relative fatigue characteristics of the two legs. Data was collected at a speed of 60 degrees per second. Results showed that the leg that buckled first had greater initial peak torques; reached 50% fatigue more quickly (peak torque); and lost range of motion (ROM) much faster than the leg that did not buckle. In one instance, the leg that buckled lost 15° ROM before the non-buckling leg lost motion. The angles at which peak torques occurred (60-90 degrees) were similar to those in normals, as reported in the literature. During normal walking, the greatest compressive joint forces and quadricep muscle torques occur between heel-strike and heel-off (average ROM - 15°). Since the buckling leg had greater peak torque than the non-buckling leg throughout the testing period, it was concluded that buckling during FNS walking resulted from lost ROM and the resulting lack of torque at knee angles above 15° of flexion.

INTRODUCTION

Studies with paraplegic subjects have been conducted using surface functional neuromuscular stimulation (FNS) to determine the rate of quadricep muscle fatigue (t-50% and t-20%) during isometric contractions (5,6). Results have shown that the stronger the initial peak torques the faster the muscles reached t-50% and t-20%. During the beginning stages of FNS fatigue ensues quickly but after several months of stimulation, quadriceps fatigue curves closely resemble those of normal muscles stimulated with FES. Kralj and Grobelnik (1973) noted t-50% in 190 sec and t-20% in 680 sec by one normal during isometric contractions of quadricep muscles with FNS. However, such isometric contractions are usually recorded with the leg positioned where the strongest torque in the range of motion (ROM) occurs (60 to 90 degrees of knee flexion).

During normal dynamic walking, the greatest compressive joint forces and quadriceps muscle torque occur between heel-strike and heel-off with knee angles between 0 and 15 degrees respectively (7). Stauffer and others (1977) noted that persons with degenerative joint disease (DJD) had less quadricep and hamstring muscle torque and fewer degrees of motion between heel-strike and heel-off. They also had non--weight bearing knee joint ROM that was independent of motion during walking. Many persons with weak quadriceps or unstable knees use plantar flexors (especially soleus) or hip extensors to help lock the knee (3) ; while others employ contralateral or ipsilateral canes (4).

The purpose of this study was to correlate ROM and quadricep muscle torque with leg buckling during walking by means of functional neuromuscular stimulation (FNS).

METHOD

Three complete paraplegic subjects (T-4, T-5, and T-8) were observed during walking with FNS and the aid of a rolling walker. Gait was clinically analyzed and the leg that buckled was recorded. Isokinetic muscle torque data was collected at 60 degrees per second because faster speeds caused the leg to hyperextend; while slower speeds generated too much torque and were less specific to angular velocity during walking. However, the percentage rate of quadricep muscle fatigue (repetitions) relative to initial peak torques is independent of isokinetic speed (2).

Data was collected to 50% of peak torque fatigue (t-50%) for both the buckling leg and the non-buckling leg; the same day the subject walked; and one to two days after the subject walked. Stimulation parameters during FNS walking were 20 mA, 0-150 μs pulse width, and 25 pulses per second. FNS parameters during Cybex testing were the same with one exception; pulse width remained constant at 150μs.

RESULTS

The leg that buckled reached 50% of its initial peak torque after 13-80 repetitions. The non-buckling leg reached 50% peak torque after 30-180 repetitions. The buckling leg lost 15° ROM after 13-40 repetitions, while the non-buckling leg loss 15° ROM after 24-80 repetitions. In all instances the buckling leg lost ROM faster and had greater initial peak torques (30-90% greater torque) than the non-buckling leg. Manual examination of the non-buckling leg showed that it had the vastus medialis and vastus lateralis contracting by means of a total of four electrodes. The buckling leg also had four electrodes that included the aforementioned muscle electrodes with combination electrodes that included the vastus intermedius.

DISCUSSION & CONCLUSION

Clinical data was collected for 20 subjects with degenerative joint disease (DJD) and/or knee instability to determine the minimum amount of torque with which one could walk. Subjects with DJD were able to walk (with the aid of a cane or crutches) despite being able to generate only 5-40 ft/lb of torque on one or both legs during Cybex isokinetic evaluation at 60°/ second. However, many of these subjects had greatly reduced knee joint motion during stance. Since flexion of the loaded knee increases both quadricep muscle forces across the knee and knee joint forces, it is quite logical for persons with muscle weakness or DJD to reduce knee joint motion during stance. Mathematical models of normal subjects, during quiet standing, have shown as little as -10 ft/lb of knee joint torque (hyperextension with no quadriceps torque) when erect and as much as 92 ft/lb in a squatting position. Subjects with DJD are able to compensate because they have the proprioception and voluntary muscle responses necessary to limit knee motion during stance; and to substitute with plantar flexors or hip extensor muscles when required.

Since paraplegic subjects have little or no proprioception, it is difficult to develop the compensatory skills of subjects with DJD. Paraplegic walking with FNS was open-loop and was not always done at a uniform speed. Slight changes in balance due to instability or uneven surfaces could cause large amounts of torque to be placed upon the knee unexpectedly. However, since the torque generated by the subjects in this study was similar to that of subjects with DJD (18-60 ft/lb)(7), it may be more appropriate to use a pathological model such as DJD or polymyositis for paraplegic FNS walking rather than a normal walking model. T-50% for FNS Cybex data ranged from 20 seconds to 2 minutes.

Consideration must also be given to implant techniques. Since stronger electrodes appear to lose ROM and fatigue faster than weaker electrodes, combination electrodes that stimulate additional muscle fibers may be inappropriate. Isometric data from the quadriceps muscles of subjects in the present study showed near perfect summation of weaker muscle groups but stronger muscle groups were no stronger than the strongest individual muscle. Since the tetanic fusion frequency of slow twitch fibers is about 20 pulses per sec (pps) and the tetanic fusion frequency of fast twitch fibers is about 60 pps (30 pps for synchronous FNS), it is unlikely that fatigue ensues as a result of fast twitch fiber recruitment (6,8). One possible explanation may be the fatigue characteristics of the individual muscles being stimulated.

Since combination electrodes were implanted in the upper half of the thigh, there was the possibility that they could have been contaminated with rectus femoris which would generate more torque at the expense of faster fatigue and hip bending. Combination electrodes could have

REPETITIONS VS.
STIMULATION TIME

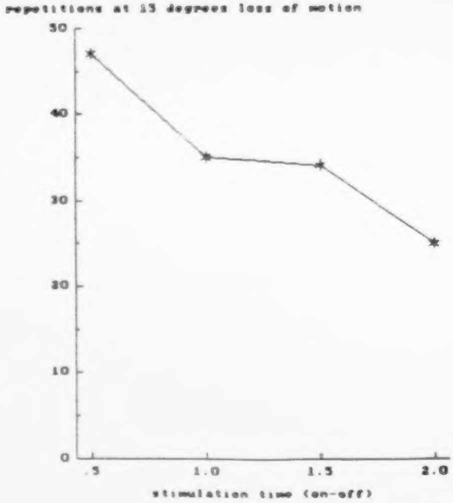

FIGURE 1

Repetitions to 50% fatigue

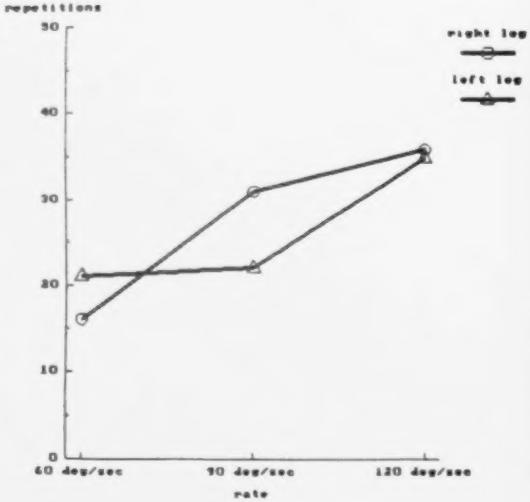

FIGURE 2

also included sartorius which would cause knee and hip flexion. Clinical observation revealed that some sartorius was present in all combination electrodes, but it did not appear significant enough to be totally responsible for the buckling and the Cybex data. More objective data (physiological) must be collected to determine the cause of muscle fatigue. In addition, closed-loop techniques must be made available to provide FNS as needed during walking and to reduce stimulation time (preliminary data from this laboratory has shown that the number of repetitions prior to t-50% and -15° ROM can be increased by decreasing stimulation time [fig 1 and 2]). This may be accomplished by increasing the speed of FNS walking (reduced stance time), ground reaction braces that allow the quadriceps to be cut off when the center of gravity passes in front of the knee, and reducing duty cycle (6). Another argument against the use of overlapping combination electrodes is the concept of rotating the fibers being stimulated while standing or walking (6) to reduce fatigue. If combination electrodes are used to rotate the muscle fibers being stimulated, there is an increased chance of stimulating many fibers continuously due to a large amount of overlap. Lost ROM is primarily responsible for knee buckling during FNS walking.

ACKOWLEDGEMENTS

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Standing by Functional Neuromuscular Stimulation in the Laboratory and the Home: Case Reports of 18 Paraplegic Individuals

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ABSTRACT

Recent interest in using functional neuromuscular stimulation (FNS) has resulted in several feasibility demonstrations in various laboratories which show the potential of this technique in carefully selected patients. A simple, two channel FNS protocol may be useful for transient periods of standing, assistance with transfers, or other activities of daily living. This paper presents case reports from a research program in which eighteen individuals participated in a research protocol for standing by bilateral electrical stimulation of the quadriceps using surface electrodes. These data suggest that a number of associated problems may exist that can interfere with the successful implementation of FNS as a standing aid. The data also indicate that there are a significant number of patients who may benefit from FNS systems.

INTRODUCTION

The application of functional neuromuscular stimulation (FNS) in spinal cord injury (SCI) has recently come under intensive investigation by a number of centers (4,6,7). Two issues which remain unclear are the usefulness of FNS in rehabilitation for a large number of patients, and the degree of FNS system complexity that can be tolerated in clinical application. Research in this area is relevant to SCI because it offers the hope of enhanced mobility.

BACKGROUND

It is possible to obtain standing in a select population of mid thoracic paraplegic individual using a very simple FNS system. Recent studies have stressed the importance of standing in this population (1). Standing is thought to help: 1) prevent joint contracture by serving as a type of range of motion exercise at the hips and ankle, 2) prevent osteoporosis by loading the long bones of the legs, 3) improve the position of the internal organs and perhaps aid bowel and bladder function, 4) reduce the chance of pressure sores by relieving pressure, 5) increase functional ability to reach while standing and 6) enhance personal esteem (1). Proposed methods for mobilization must provide reliable standing function. The main objective of this research is to gather data on the utility of and the problems associated with standing by FNS. While it might appear that this technique would be eagerly anticipated by paraplegic individuals, this must be supported with data and experience. Concern with this issue is justified by the rejection rate of knee-ankle-foot orthoses (3). The importance of mobilization to the paraplegic individual has recently been studied (5).

METHODS

Muscle Restrengthening:

The initial phase of participating in this research project is a stimulation protocol designed to restrengthen paralyzed muscles. After training, subjects follow the protocol without direct supervision. Followup visits are made to monitor patient compliance at least two times per month. The stimulators used are locally designed and constructed for research purposes. Stimulation parameters are pulses of 0-120 volts, 20 Hz frequency, and 0.4 ms pulse width. The electrodes are carbon rubber. A thin water soaked sponge is used in place of electrode gel. Elastic straps are used to hold the electrodes in place. The purpose of the stimulation is to increase muscle bulk and strength. Stimulation begins with 2 five minute daily sessions and progresses to 2 sixty to ninety minute sessions daily.

Since the optimal procedure for muscle restrengthening is not yet known, a 1:1 duty cycle of stimulation on/off with the quadriceps being alternately stimulated is used. The quadriceps is the most important muscle group in this study; primary emphasis is on this muscle. The typical procedure for restrengthening is to have the subject recumbent, elevate the knees about 25 to 30 cm, and stimulate the quadriceps, alternating right and left.

Standing:

Once subjects had restrengthened their muscles, the feasibility of standing by FNS is explored. Most subjects demonstrated their capability to stand in the clinic by knee-ankle-foot orthoses (KAFO). Standing by FES can be achieved by a minimum of two channels of stimulation. This simplicity is clinically attractive. The knee joints are stabilized by bilateral quadriceps stimulation. Upon assuming upright posture, the hips are kept in hyperextension, the so-called "C-curve" posture (2). No stabilization was provided at the ankle joints. This necessitates reliance on external balance aids such as parallel bars or walkers. The stimulator design concept was similar to that of the Ljubljana group (6). However, this unit has been designed for standing only, to reduce the number of control knobs and switches. The stimulator assumes the sitting mode when first switched on. The command sequence is a toggling between the sitting and standing modes. A pair of surface electrodes is applied to each quadriceps femoris muscle. The electrodes are connected to a single locking connector on the rear of the stimulator. In practice, it has been found that essentially the same stimulus intensity for both right and left legs will produce acceptable standing. The stimulator is turned on by the OFF-ON/AMPLITUDE knob on the front panel. The stimulation amplitude is adjusted by this front panel control and can be continuously varied. This knob has two LEDs above it that indicate the presence of stimulation current through the electrodes. To effect standing, the POSTURAL CHANGE button on the right of the front panel is depressed. A two-second delay occurs while the patient prepares for standing, an audible warning is sounded, and the stimulation begins. This allows the subject time to position his hands to assist with standing to obtain better synchronization of upper body action with the gradual onset of stimulation. Pulse amplitude is increased linearly over the first two seconds to the level set by the amplitude control, while the pulse width is kept constant at 0.40 ms. This causes a smooth onset of quadriceps contraction and transition to a standing posture. To sit, the POSTURAL CHANGE button is again depressed. A two-second delay occurs, the audible warning is sounded, and the stimulation amplitude is decreased over the next two seconds to effect a smooth transition to a seated posture.

Summary of Results

A total of eighteen patients have achieved standing by FNS. For the purposes of this study, standing was defined as the ability of the subject to stand in the parallel bars with bilateral stimulation of the quadriceps with more than 90% of the body weight supported by the legs. This was verified by having the subjects release both hands for brief 1-2 second periods and quantitative measurements on force plates or scales. Four of the eighteen were able to stand with sufficient confidence that they were allowed to stand outside the laboratory. This was done in the home with the aid of a standing frame. The standing frame had a padded bar to support the knee in case of collapse, as shown below. Typically, subjects stand for several periods of 5 to 15 minutes per day, two to five days per week. Fourteen of the eighteen were able to demonstrate standing only in the laboratory. These individuals were not permitted to stand outside of the laboratory for a number of reasons. However, three of these individuals are expected to begin standing at home after a longer training period. None of the subjects reported adverse consequences of the stimulation, such as skin burns, increases in spasticity, or other complications.

Abbreviations are: GSW=gun shot wound, MVA= motor vehicle accident, ypi= years post injury at entry to the program, yo= years old, inc=incomplete injury, comp=complete injury, highest level of motor injury on either right or left side given as T=thoracic or C=cervical.

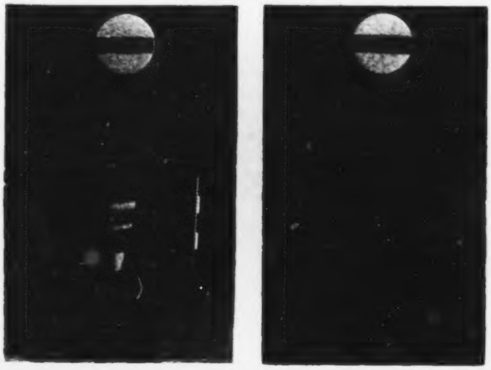
Case Reports: Home Standers

Case 1: 39 yo black male, T5 inc GSW, 3 ypi. He was prescribed KAFO and used them several times per week for therapeutic standing. He could ambulate, but gave this up because it was too tiring. His primary problem was modest ankle platarflexion and hip flexion contractures, which interfered slightly with his maintaining a comfortable posture when standing. There were no other complications to interfere with FNS.

Case 2: 36 yo hispanic male, T6 comp MVA, 5 ypi. He was prescribed KAFO and used them several times per week for therapeutic standing. His primary problem was equinovarus of the foot while standing.

Case 3: 44 yo white male, T4 inc GSW, 1 ypi. He was prescribed KAFO and used them several times per week for therapeutic standing. His primary problem was flexor spasticity while standing.

Case 4: 25 yo white male, T6 comp GSW, 1 ypi. He was prescribed KAFO and used them several times per week for therapeutic standing. His primary problem was spasticity while standing, which interfered with his posture in the trunk. He also had previously existing problems with pain and a recurrent UTI which aggravated the spasticity.



Case Reports: Lab Standers

Cases 5 and 6 were both incomp C7 MVA. Case 5 was a 33 yo white female. She had a severe hip flexion contracture. She was not prescribed KAFO and had very poor standing balance. Case 6 was a 39 yo black male. He was being fitted for KAFO for therapeutic standing. His standing balance was very poor. Both cases 5 and 6 showed excellent contraction of the quadriceps to FNS, but poor trunk control and upper extremity weakness prevented them from successful standing.

Case 7: 28 yo white male, T1 inc MVA. He was prescribed KAFO and used them extensively for standing and limited mobility. His trunk control was good. He is likely to become a home stander.

Case 8: 46 yo black male, T3 comp GSW, 7 ypi. He was prescribed KAFO and used them several times per week for therapeutic standing. His muscles responded to FNS, but never developed sufficient fatigue resistance to enable standing for longer than 30-60 seconds. His upper extremities were also weak.

Case 9: 30 yo white male, T3 comp, fall. He was prescribed KAFO and used them several times per week for therapeutic standing. He was 1 ypi. He stood by FNS on his first visit to the laboratory, and is likely to stand at home.

Case 10: 47 yo white male, T4 comp, spinal cord bleed. He was not prescribed KAFO. He had poor upper body strength and trunk control.

Case 11: 33 year black male, T4 comp GSW. He was obese and had poor trunk control. He was not prescribed KAFO. He had a leg length discrepancy and chronic decubiti.

Case 12: 20 yo white male, T5 inc MVA. He was prescribed KAFO and used them several times per week for therapeutic standing and mobility. He has good standing balance and will probably become a home stander.

Case 13: 39 yo hispanic, T5 comp, aircraft accident. He was prescribed KAFO but uses them infrequently. He is also suspected for substance abuse. He is slightly overweight and has poor trunk control.

Case 14: 31 yo black male, T6 comp MVA, 13 ypi. He has severe ankle and hip contractures. He has not complied well with the protocol.

Case 15: 47 yo white male, T11 comp. He had severe problems with pain which existed prior to entering this research program. This limited his ability to participate in the protocol. He had a spinal cord stimulator implanted for pain control, and was considering other operative procedures.

Cases 16, 17, and 18 were individuals who moved too far away from the laboratory to continue participating in the program. All achieved reasonable standing in the laboratory. All were white males, complete injuries, ages 22, 29, and 29, levels T4, T5, and T7. All were prescribed KAFO and used them several times per week for therapeutic standing and mobility.

DISCUSSION & CONCLUSION

The data indicate that a significant number of individuals with thoracic spinal cord injury may be able to use simple FNS systems for standing. The benefits that might be derived from such standing remain to be established by further research. With respect to selection criteria, it appears that successful use of KAFO and appropriate response of the quadriceps to electrical stimulation are the most important criteria for successful use of FNS. The data also suggest that a number of associated medical, psychological and social problems may exist that can interfere with the successful implementation of FNS as a standing aid.

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IMPLEMENTING TRUNK CONTROL IN FNS WALKING SYSTEMS

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ABSTRACT

In implementing trunk control in functional neuromuscular stimulation (FNS) walking systems we had assumed that paraplegic subjects with injuries below the T-10 level would be able to combine voluntarily controlled back muscles with computer-stimulator controlled lower muscles. Walking trials with subjects with injuries both above and below the T-10 level have demonstrated that coordination of the two sets of muscles is better done with electrical stimulation, even for the subject with injury below the T-10 level. Our T-11 subject found that attempting to coordinate voluntary back muscle activity with computer-controlled hip and leg muscle activity required a degree of concentration which would prevent FNS-assisted walking from become a routine activity.

INTRODUCTION

Successive demonstrations have shown increasing potential for the use of electronic orthotic systems to restore function to paralyzed muscle, (1,3,4,6) heightening the importance of wise selection of muscles for stimulation. Prior communications from this and other laboratories have stressed the importance of stability, minimum energy costs, minimal complexity and maximal user safety in functional neuromuscular stimulation (FNS) systems (2,6).

We have hypothesized the importance of control of the trunk in addition to the hip, knee and ankle. In implementing trunk control during FNS walking of paraplegic subjects (T-4 to T-11), we hypothesized in addition that the subjects with essentially normal spinal control (injury below T-10) would be able to function well with only ankle, knee and hip control; combining the voluntarily-controlled spinal muscles with the computer-controlled lower muscles. We predicted that individuals with higher level injuries than T-10 would need computer control of the spine in addition.

MATERIALS AND METHODS

A forty year old T-9 level paraplegic subject was chosen to represent the higher injury level subject. He had been a regular participant in the Cleveland Veterans Administration computerized walking project since February of 1984. His lesion was complete with no residual sensation or motion below his stated level. To stimulate muscles controlling the hip, knee and ankle percutaneous intramuscular wire electrodes were implanted in the muscles shown in Figure 1. A 32-channel microprocessor controlled stimulator (7) was used for both intramuscular and surface stimulation; a typical stimulation pattern is shown in Figure 1. The subject first walked with functional neuromuscular stimulation in May of 1984.

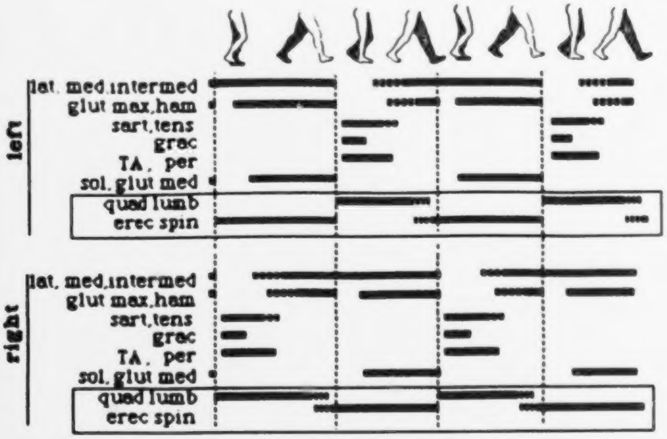

FIGURE 1: Stimulation pattern for walking. The following muscles are stimulated with percutaneous intramuscular electrodes: vastus lateralis, vastus medialis, vastus intermedius, gluteus maximus, hamstrings, sartorius, tensor fasciae latae, tibialis anterior and peroneus longus, soleus, gluteus medius. The quadratus lumborum and erector spinae are stimulated by means of surface electrodes.

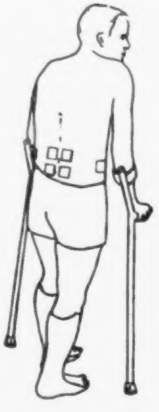

FIGURE 2: Placement of surface electrodes for stimulation of erector spinae and quadratus lumborum muscles.

Trunk stimulation was accomplished using surface electrodes placed on the back to recruit the quadratus lumborum and erector spinae. The subject was asked to walk a 15.4 meter course three times using a rolling walker. All trunk electrodes were then disconnected and the subject again walked the course three times. For each walk, the time to complete the course was recorded. Both the therapist and the subject recorded their subjective comments.

The evaluation was repeated for a 29-year old subject with a T-11 level injury, also with no residual motion or sensation. He had entered the research program in July of 1983 and had first walked in August of 1983.

RESULTS

No statistically significant difference was noted either in the speed of any individual walk or in the combined walks with trunk stimulation versus without trunk stimulation. The therapist reported no qualitative difference between the two series of walks. The subjects reported less dependence on the walker and on their arms. There was no difference in response between the T-11 and the T-9 subjects.

DISCUSSION

While the similarity of response for subjects with different injury levels was initially surprising, careful review of the facts supported the outcome. Time relationships in gait are extremely critical. Variations of only a small fraction of a second in the application of forces can result in large response differences. The normal nervous system usually has no difficulty in coordinating all the muscles that are active during the gait cycle. However, learning to function with a system consisting of a brain-controlled upper body and a computer-controlled lower body appeared to present at least the difficulty of developing a tennis or golf stroke. The function achieved was far from natural even for the T-11 subject after repeated attempts. There was improvement with practice but it appeared that such an interaction would always require intense mental effort and would never become the automatic type of control enjoyed by the normal human in walking.

The best solution found was to allow the computer to control both the normal and paralyzed muscle so that precise integration could occur without conscious effort from the subject. The stimulation was well tolerated even though normal sensation was present. These results suggest that an acceptable device for routine walking should not require intense concentration and highly skilled interaction.

We suggest that this is another example of the basic lesson documented by the difficulties experienced in controlling the IBM Model I electric arm (2). Initially, the developers felt that since humans have no problem learning complex skills such as typing, that they would have no problem in controlling a device such as the Model I with multiple degrees of freedom. The actual result was that a few patients were able to become proficient with the device but that it required much training and much concentration to use. It became obvious that the device would never be useful as an arm prosthesis.

ACKNOWLEDGEMENTS

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EXPERIENCE WITH ANKLE-FOOT ORTHOSES AND PARAPLEGIC SUBJECTS USING FUNCTIONAL NEUROMUSCULAR STIMULATION

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ABSTRACT

Paraplegic research subjects walking with functional neuromuscular stimulation have been fitted with ankle-foot orthoses (AFOs) (3). Although devices performed well to keep the foot from inverting and thus to prevent major injuries, several incidents of blisters and a fifth metatarsal fracture spurred revision of the original design. Two paraplegic subjects presently use the newly designed orthosis which is undergoing evaluation. Heel switches are now routinely incorporated into the orthoses and used to trigger sequential stimulation patterns in the microprocessor-controlled muscle stimulator.

INTRODUCTION

Paraplegic research subjects using a laboratory FNS system continue to walk with ankle-foot orthoses (AFOs) specifically designed to prevent the foot from inverting; a condition which may allow injury to occur to the ankle and foot structures (2). The AFO is also intended to impede the development of degenerative joint disease related to extensive use of a joint with no sensory feedback. Some subjects exhibit severe ligamentous laxity about the ankle while others tend to invert the foot with muscular action. Moreover, we expect users of the clinical FNS system to be community ambulators, encountering terrain which is uneven and unlevel at times. At present, closed-loop feedback control of the foot in the coronal plane has not been accomplished. Therefore, the application of AFOs to stabilize the foot has been a simple and effective solution to the problem. Experience with these orthoses over the last year and a half has guided revision which has resulted in improved efficacy and saftey.

PAST DESIGN

Four complete paraplegic subjects and one partially paralyzed individual have used the AFO approximately four days a week, walking 200 to 1000 feet per day, for the past 18 months. The orthosis maintains the subtalar joint in a neutral position and supports the longitudinal arch; which are significant biomechanical factors in preventing acute and chronic destruction to the bones and articulations of the foot. The past design was observed to adequately maintain the foot and ankle neutrally in the coronal plane. However, blisters and a fifth metatarsal fracture occurred while subjects were wearing the orthoses. Alterations to the past design were made to address these problems.

EXPERIENCE

One of the paraplegic subjects participating in the FNS research at the Cleveland VAMC developed a fracture at the base of the fifth metatarsal shaft while wearing AFOs bilaterally. Investigation into the matter revealed two factors predisposing the subject to this type of injury. First, mediolateral positioning of the subject's hip joints during ambulation was such that on many steps the hip excessively adducted during swing phase or the foot planted the ground in the proper position, but then the hip musculature would allow the pelvis to shift to the side of the stance leg. In both instances the stance leg remained adducted throughout the forward progression of the center of gravity. In normal human locomotion, excessive stance leg adduction does not occur because balance would be altered, forcing the individual to stumble or fall. However, during ambulation with crutches or a walker it is possible to maintain an upright posture by means of these external supports despite an overly adducted stance leg. Secondly, the orthosis is unyielding in the medio-lateral plane, i.e. inversion and eversion is restricted. Given these conditions the weight of the body less arm support is distributed solely along the lateral border of the foot (figure 1b). Since the orthosis supports the lateral border along the entire length including the fifth metatarsal head, a three-point force system develops (figure 1c). This arrangement of conditions and forces seems to logically explain the cause and location of the fracture.

A reasonable solution to this problem, given that hip angle in the coronal plane can vary unpredictably into "extreme" ranges, is to allow the foot to adapt to adduction angles through eversion (figure 2). Foot eversion will restore pressure to the plantar aspect of the fifth metatarsal as well as distribute weight to the rest of the foot, thus diminishing a potentially injurous condition.

Blisters have occurred directly over the navicular tuberosity due to its prominence and overlying thin skin. Although blisters are less serious in nature than bone fractures, healing is slow and may prevent further use of the orthosis until the wound heals. These blisters were not caused so much by the lack of pressure relief, but, by the degree to which the orthotic material did not encompass the dorsal one-half of the navicular tuberosity. On several occasions, addition of as little as one-sixteenth of an inch Sorbothane, added to increase the insole thickness, led to the development of blisters. This indicates the critical aspect of properly fitting orthoses and emphasizes that they should not be tampered with after a satisfactory fit has been obtained.

One other source of blisters seen in our subjects is the bulging of tendons as their muscles are stimulated. This has been a problem for one paraplegic subject. In his case, the tibialis posterior tendon bulges from the medial aspect of the foot as it traverses the posterior-superior aspect of the navicular tuberosity. This muscle is not selectively stimulated, but receives "spill-over" from the soleus electrode as the electromagnetic field increases due to pulse width increase. A channel relief was made in the orthosis for the tendon, thus alleviating the skin breakdown.

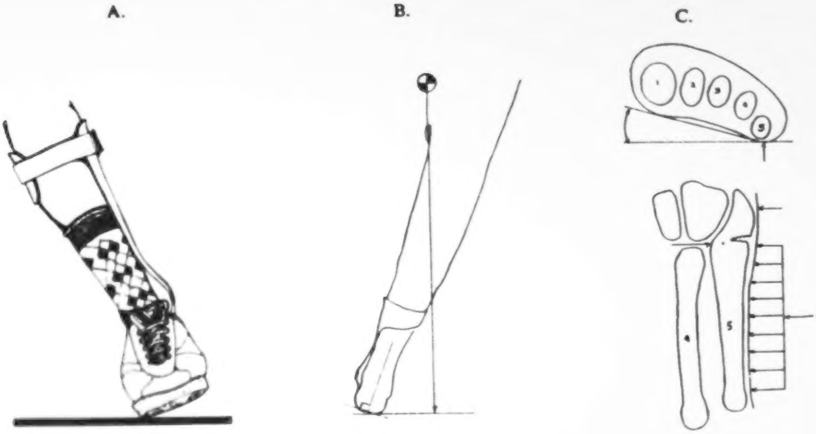

FIGURE 1

A. Leg is adducted relative to the ground, foot being held neutral by rigid orthosis.
B. Back view of foot in rigid orthosis; weight of body is distributed to the lateral border of the foot.
C. Forces which may cause metatarsal fracture: above, front view through metatarsal shafts; below, partial dorsal view.

REVISIONS

The new orthotic design is similiar in basic construction, but has significant advantages over the old one. Whereas the old design rigidly fixes the foot in the coronal plane, the new design allows eversion to occur. This was accomplished through modification in lay-up technique. Unidirectional carbon fiber tape is draped over the inverted cast of the subject's leg from the medial to the lateral aspect of the foot and in succession from heel to metatarsal heads. This lay-up produces a "U-shaped", rigid foot insert. When connected to the stainless steel joint and medial upright the unit rigidly fixes the subtalar and tarsal-metatarsal joints; hence inversion and eversion are restricted. Splitting the carbon fiber tape along the length of the foot at the junction of the medial and plantar surfaces produces a "hinge" after the lamination and trim out are completed. Hinging the foot orthosis in this manner allows eversion to take place due to increased flexibility. Less flexibility is imparted to the heel area than the forefoot due to more fiberglass being used in the heel area. Therefore, hindfoot abduction is limited in degree while adduction is still prevented.

The mechanical ankle joint is no longer aligned according to axis of rotation data from Isman and Inman from their anthropometric studies (1). Alignment in this manner tended to cause inversion of the foot in plantarflexion. Instead, the joint head is arranged parallel to the longitudinal axis of the foot in the horizontal plane and perpendicular to the floor in the coronal plane.

Heel switches arranged in triangular formation and connected in parallel are now routinely incorporated in the orthoses. Switches are embedded in Sorborthane insoles. This triangular layout enables triggering of at least one switch when the leg is adducted or abducted upon heel strike.

RESULTS

Two paraplegic subjects use the newly designed orthoses on a regular basis. When the subject's hip is in adduction the foot adapts to the floor by everting. While some forefoot inversion is now possible, it is minimal. Repositioning of the ankle joint has not adversely affected the alignment. Heel switches incorporated into the orthosis respond to heel strike even when the leg is adducted or abducted with respect to "normal" hip alignment during gait.

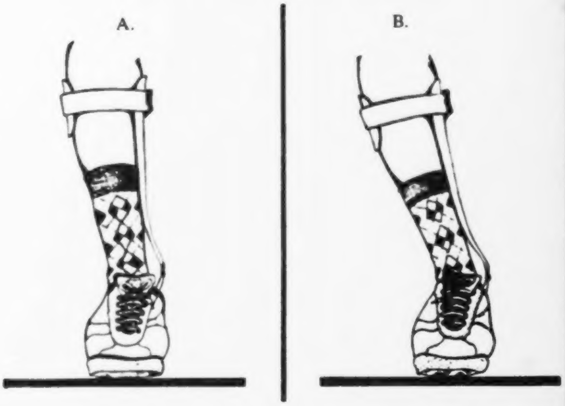

FIGURE 2

A. Leg is neutral relative to the ground.
B. Leg is adducted relative to the ground; foot remains flat on floor.

DISCUSSION

Ankle-foot orthoses are used to prevent acute and chronic injury resulting from excessive inversion of the foot and from walking with insensitive joints. Some revision to the AFOs has been necessary to increase the safety factor when subjects walk using FNS. The increased flexibility in the orthosis is more physiologic and may in fact be advantageous. Flexibility allows some supination of the foot to occur during late stance phase to increase the rigidity of the arch. The possibility of eversion allows for variances in hip angle in the coronal plane which may reduce the incidence of injury to the foot. Modification of design has been possible by altering the lay-up of composite materials. As we gain even more experience we expect further revisions to take place.

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THE EFFECTS OF FNS ON DISUSE OSTEOPOROSIS

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ABSTRACT

CT scans of the diaphysis and metaphysis of the femur of able-bodied persons and paraplegic persons treated with and without functional neuromuscular stimulation (FNS) were performed. Scans of 2 mm thickness were made on a Technicare HPS system and then analyzed with a specially developed computer algorithm. Serial quarterly scans were obtained for the FNS user paraplegic group while single scans were obtained for the two control groups - non-FNS user paraplegics and normals. Results showed a significant difference in bone mineral density among the three groups. The FNS group's cortical bone density was 3.4% less than the normal group while the paraplegic control group was 9.5% below normals ($p<.002$).

INTRODUCTION

Disuse osteoporosis is a loss of bone mass resulting from muscular inactivity and/or reduction in weight bearing. In clinical medicine such bone atrophy usually occurs after a fracture necessitating varying degrees of immobilization; after paralysis resulting from conditions affecting the central nervous system, the spinal cord or the peripheral nerves; after muscular inactivity due to disease of joints and muscles; or after any long-standing systemic debilitating disease. Because of osteoporosis, fractures are not uncommon in paralyzed people (3). A significant number of these fractures involve the lower third of the femur and tend to occur with relatively minor trauma (7).

According to a well know orthopaedic principle, Wolff's law, the internal architecture and external conformation of bone respond to its strain history. Disuse osteoporosis is a manifestation of Wolff's law in the negative direction. There is evidence that increased functional loading will hypertrophy normal adult bone (1,6). In addition it has been clearly demonstrated in experimental animals that bone placed under increased weight bearing and muscular stress will hypertrophy in response to that stress (5,8). We believe that functional neuromuscular stimulation can be used to provide enough muscular stress to have a positive effect on disuse osteoporosis.

METHODS

There are various noninvasive methods to assess the mineral content of bone. Standard radiographs of bone are not accurate or sensitive for quantitative measurements. Photon absorptiometry and gamma-ray CT are primarily limited to smaller bones near the skin surface. The software quantification of X-ray CT scanners is based on the work of Cann and Genant (4) which measured the trabecular bone of the spine. A new software analysis package was developed at Technicare Corporation to quantify cortical bone and trabecular bone of the appendicular skeleton. According to the accuracy of the calilbration equation it is sensitive to changes in bone density as small as 1%. In vitro testing with excised bovine and human bone have been accurate to within 1.5%.

Three groups of subjects were selected for this study: paraplegic FNS users, paraplegic non-FNS user controls, and normal controls. The first group were six paraplegic subjects (ages 24 to 39 years) who regularly use functional neuromuscular stimulation in the research program "Walking Restored in Paralyzed Man Using Electronic Orthotics" at the Cleveland Veterans Administration Medical Center. They had percutaneous intramuscular electrodes implanted in the following muscles: quadriceps femoris, sartorius, tensor fasciae latae, gracilis, hamstrings, gluteus maximus, gluteus medius and the posterior portion of the adductor magnus. These paraplegic individuals had muscle stimulation for at least six hours per week and weight bearing at least three times per week. Their muscle strength was measured on a Cybex dynamometer. The strength of the quadriceps ranged from 54 to 108 Nm isokinetically. Individually, the strength of the hip extensors ranged from 7 to 41 Nm isometrically.

The first control group were seven paraplegic individuals (ages 25 to 72 years) who had not been exposed to FNS, although a few had experienced weight bearing in long leg braces. The second control group were seven normal subjects who are weight-bearing bipeds from between 24 and 45 years of age.

The CT scan protocol consisted of a 2mm slice thickness of the mid portion of the femur. Two contiguous 2mm slices were taken at the epiphysis of the distal femur. The results of this papaer are concerned only with the midshaft of the femur. The total dose per study was less than 2 rads. The control subjects were scanned once; the FNS group was scanned every three months over a nine month period.

RESULTS

Among the three groups there was a significant difference in bone mineral density. The FNS group fell between the normal control group and the paraplegic control group. Their cortical bone density was 3.4% less than the normal group while the density for the non-FNS paraplegic group was 9.5% below normals ($p<0.02$). It is interesting that the mean cortical thickness was not significantly different among the three groups although there was a definite decrease in the paraplegic group means. We attributed the lack of significance to individual variations in bone type since this measurement was not normalized.

The most interesting result was found in analysis of the dense bone. The area of this core, represented as a percentage of total bone area, was significantly different among the three groups. Forty-three percent of the FNS group's midshaft was within this core, compared to 52.9% in the normal group. This corresponds to a 19% loss of dense bone in the core of the midshaft. The control paraplegics had only 33% of their bone within this core, a 38% loss from the normal group.

DISCUSSION

Disuse osteopoprosis is a well-recognized and documented clinical entity which results in a major bone loss in the affected limbs. In a general way, bone loss in the lower extremities is related to a reduction of a) strain normally associated with axial loads and bending moments, b) pressure of the musculature against the periosteum, and c) tension in the fibrous tendon insertions. By using FNS to stimulate the muscles surrounding the femur and by getting the subjects to stand and walk, we feel that we have reversed the bone loss. The factors which may play a role in limiting reversal of the effects of disuse in the FNS treated subjects include insufficient forces produced by the stimulated muscle, insufficient time for standing and walking exercise and factors other than the hydrostatic forces associated with walking.

CONCLUSION

The results of this study indicate that FNS provides some type of bone stimulation that improves the osteoporotic state arising from disuse. Still the FNS group does not have the same density or distribution of bone mineral as the normal group. These results indicate that constructive cortical bone remodeling occurs in response to the stress of muscle stimulation with associated weight bearing.

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FUNCTIONAL ELECTRICAL STIMULATION OF HIP EXTENSION AND ABDUCTION AFFECTED BY ACTIVITY OF THE TRUNK

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ABSTRACT

Abduction and extension movements of the hip are accompanied by activity of trunk muscles in normal subjects. We tested for electromyographic (EMG) activity in muscles controlling lateral flexion, flexion and extension of the trunk during maximum isometric hip abduction and extension effort in a normal subject. Ipsilateral erector spinae and quadratus lumborum muscles showed the most EMG activity during hip abduction. The erector spinae bilaterally were most active during hip extension. In three paralyzed subjects with spinal cord injuries at levels between T-7 and T-11, we measured torques of hip abduction and extension produced by electrical stimulation both with and without trunk stimulation. We found that stimulation of the trunk muscles shown to be most active in the normal subject increased hip extension torque by at least 40% and abduction torque by more than 30%. These results indicate that trunk control should be included in any effective hip controller which is a part of a lower extremity electronic orthosis for restoring functional tasks in paralyzed people.

INTRODUCTION

Although maximal muscle forces are not required during normal gait (1), it has been clearly demonstrated that impairment of any of the major muscle groups of the trunk and lower limbs will reduce symmetry and stability of gait, thus increasing the energy cost of ambulation (2). This observation applies particularly to muscles acting at the hip and ankle joints which perform most of the work during normal gait (3). For example, a minimum degree of abduction torque is required to maintain the pelvis in a level position during single-limb support. If not available, the familiar lateral lurch associated with abductor weakness appears (4,5).

In paralyzed subjects using functional electrical stimulation (FES) we found that stimulation of hip extensors, hip abductors and plantarflexors increased the stride length and speed of walking and decreased the time of double limb support and the weight put onto the walking aid (6). The stronger the contractions of these muscles, as measured by manual resistance and their ability to overcome gravity, the easier it was for the subjects to walk (7). Recently, the addition of trunk muscle stimulation during walking has increased the subjects' perceived stability and resulted in a smoother gait.

Studies of normal walking (8) and strength testing of hip extension and abduction (5) have shown that muscles effecting trunk extension, trunk lateral flexion, hip extension and hip abduction are active concurrently. This study was designed to confirm the activity of the trunk muscles during normal hip extension and abduction and to determine their effect on hip extension and abduction strength in paralyzed subjects.

METHODS

First, the activity of the trunk muscles was studied during maximum isometric torque measurements of hip extensor and abductor muscles using a Cybex II unit (Lumex, Ronkonkoma, NY). Surface electrodes with built-in preamplifiers were used to detect electromyographic activity of trunk muscles in a normal male subject. The EMG signals were amplified, band pass filtered (20Hz-500Hz) and recorded on a fiber optics chart recorder (Honeywell model 185B CRT Visicorder). Because the number of electrodes was limited to six, five series of tests were conducted. In all tests, EMG records were collected from the following four muscles; left and right quadratus lumborum, and left and right erector spinae. The fifth and six electrodes were changed after each series enabling EMG records to be collected from the left and right gluteus medius muscles, the left and right rectus abdominis muscles, the left and right semitendinosus muscles, the left gluteus maximus muscle and the left tensor fasciae latae. Isometric hip extension torque measurements were made with the subject in a supine position with the test limb at 45 degrees of hip flexion (the approximate hip angle at heel strike during gait where these muscles are most active). Abduction torques were tested with the subject lying on his side with the test limb at 0 degrees of abduction. In both tests, a wide velcro strap positioned securely at the upper level of the pelvis served to stabilize the subject on the Cybex testing bench.

Second, the effects of trunk activity on hip extension and abduction torques were tested in three paraplegic subjects who were participants in our research program on the restoration of ability to perform functional tasks using FES (9). Their injury levels ranged from T-7 to T-11. Of the three subjects tested, one (T-7) had no voluntary control of his trunk, one (T-8/9) had some control of his upper abdominal muscles and one (T-11) had almost complete control of his trunk apart from his lower back muscles. They all had percutaneous intramuscular electrodes implanted in their hip extensors including the gluteus maximus, posterior portion of adductor magnus and semimembranosus or semitendinosus. Electrodes in the hip abductors included the gluteus medius and tensor fasciae latae. Other muscles in the lower limbs were also instrumented and are described elsewhere (10). Surface electrodes were placed over the left and right quadratus lumborum, erector spinae and rectus abdominis muscles to provide lateral flexion, extension and flexion of the trunk respectively.

The stimuli were constant current, 20mA in amplitude, charge-balanced, biphasic pulses. Muscle contractions were controlled by modulating pulsewidth from 0-150 microseconds and frequency from 18-50 Hz for the percutaneous electrodes. For transcutaneous stimulation, the amplitude was varied up to 90 mA and the pulsewidth was set at 250 microseconds. A series of stimulation patterns were programmed in the subjects' portable 32-channel microprocessor controlled stimulators. The paraplegic subjects were positioned and stabilized on the Cybex testing bench in the same manner as the normal subject tested for EMG activity. When activated by the subject, the stimulator would automatically cycle between various stimulation patterns with a 20 second rest period between each trial of hip extension or abduction. The knee was extended by stimulation of the quadriceps during all tests. The stimulation patterns included the following combinations of trunk activity during hip extension: a) bilateral stimulation of the quadratus lumborum, erector spinae and rectus abdominis, b) bilateral stimulation of the erector spinae, c) ipsilateral stimulation of the erector spinae, and d) contralateral stimulation of the erector spinae. During hip abduction ipsilateral stimulation of the quadratus lumborum and erector spinae was tested for its effect on generation of torque. The effect of fatigue on data interpretation was eliminated by cycling several times between two patterns of activity which were to be directly compared. Thus, fatigue, if it occurred, would affect the muscles common to both patterns to the same degree. The difference in hip extension or abduction torque for each pair of patterns was thus attributed to the influence of the trunk.

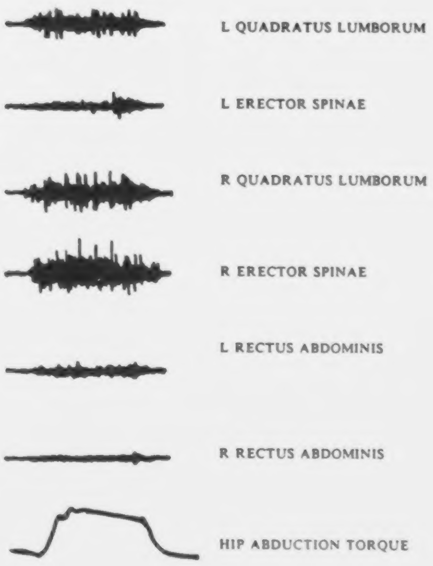
RESULTS

EMG data recorded during testing of maximum isometric hip abduction torque (Figure 1) indicate that in addition to the activity of the gluteus medius, the ipsilateral quadratus lumborum and erector spinae were the most active trunk muscles. Less activity was detected in the contralateral quadratus lumborum and gluteus medius. Only a trace of activity was observed in the rectus abdominis bilaterally and in the contralateral erector spinae.

During a maximal isometric hip extension effort, EMG activity (Figure 2) was observed in the ipsilateral hamstring, gluteus maximus and tensor fasciae latae muscles. A trace of activity was recorded from the gluteus medius. The most active trunk muscles were the erector spinae bilaterally. A trace of EMG activity was observed in the quadratus lumborum bilaterally.

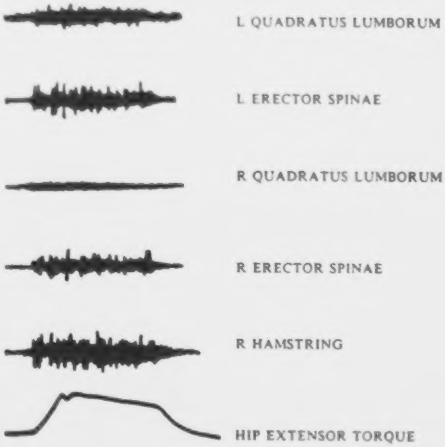
In testing for hip abduction torque in paraplegic subjects, we observed that adding ipsilateral stimulation of the erector spinae and quadratus lumborum to the stimulation of the gluteus medius increased the torque by approximately 30% in all subjects.

Hip extension torques in the T-11 paraplegic subject increased by approximately 40% with bilateral stimulation of lower back muscles and approximately 20% with contralateral stimulation of erector spinae. Ipsilateral stimulation of the lower back muscles had no effect on hip extension torque. Stimulation of the quadratus lumborum and rectus abdominis bilaterally, in addition to the lower erector spinae showed no further increase in the hip extension torque. During several trials, the subject volitionally contracted his trunk muscles in conjunction with the lower back stimulation. This maneuver increased hip extension torque above that observed with stimulation of lower back alone, but this finding was inconsistent. In the T-8/9 paraplegic subject, hip extension torque approximately doubled with bilateral stimulation of the erector spinae in addition to hip extensors. In the T-7 paraplegic subject, hip extension torque increased by approximately 50% with addition of bilateral stimulation and 20% with contralateral stimulation of the erector spinae.



R HIP ABDUCTION

FIGURE 1



R HIP EXTENSION

FIGURE 2

Maximum isometric torque values for the three paraplegic subjects are given in Table 1. Results from the tests which incorporated volitional effort are not included. Hip abduction torques are not corrected for gravity. No hip abduction data is available for the T-7 subject. It was noted, however, that the addition of trunk stimulation to gluteus medius stimulation in this subject produced greater elevation of the limb against gravity.

MAXIMUM ISOMETRIC TORQUES (FT-LBS)

Subject	Hip Ext	Hip Ext & Trunk	Hip Abd	Hip Abd & Trunk
T-11	54	75	39	46
T-8/9	36	59	32	42
T-7	38	54	n/a	n/a

TABLE 1

DISCUSSION

When the normal subject performed a maximum isometric abduction effort, EMG data indicated that the ipsilateral erector spinae and quadratus lumborum were the most active trunk muscles. This was consistent with the results from the testing of paraplegic subjects where ipsilateral stimulation of the erector spinae and quadratus lumborum in conjunction with gluteus medius stimulation increased abduction torque over that recorded with gluteus medius stimulation alone. Similarly, when the normal subject performed a maximum isometric hip extension effort, the most active trunk muscles were the erector spinae. Bilateral stimulation of the erector spinae muscles in the three paraplegic individuals produced considerably greater torque than that recorded during stimulation of the hip extensors alone. The different increases observed for hip extension torque due to trunk stimulation in different subjects were probably due to differences in both stimulated back strength and in hip extension strength. The variable results observed when the T-11 subject attempted to volitionally stabilize his trunk in conjunction with lower back stimulation may reflect his inability to co-ordinate his efforts with the activity produced by the stimulator.

The findings from this study are in agreement with data published by Murray and Sepic (5) on voluntary hip abduction that emphasize the assistance of the ipsilateral trunk activity for optimizing hip abductor function. This is of relevance both to rehabilitation clinicians and to researchers developing FES systems for the restoration of mobility in persons with upper motor neuron lesions. Further investigations of the relationship between trunk activity and hip abduction /extension in paraplegic subjects are currently underway. Of particular interest will be the role of training for co-ordination of volitional efforts in subjects with low thoracic lesions.

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A COMPARATIVE STUDY OF THE FUNCTIONALITY OF THE SECOND GENERATION OF PERONEAL STIMULATORS

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ABSTRACT

In this paper the results of a comparative analysis of functionality for three different types of peroneal stimulators, which were all developed in Ljubljana (FEPA-10, MICROFES, IPPO), are presented. In the last 10 years these stimulators have been used in about 1000 patients, either during primary rehabilitation treatment or for permanent use. To measure the functionality of the stimulator some qualitative and quantitative data were gathered over this period. The basic parameter is the average time spent using the stimulator , which depends on the parameters of stimulation, control principles of stimulation sequences (constant rate, walking rate dependent (WDR) reliability of the device and encumbrance level. Our studies shows that Microfes is much more acceptable than FEPA-10, while the functionality of IPPO is much better than the other two devices.

INTRODUCTION

Since the invention of functional electrical stimulation as a rehabilitation method, its application in a non-clinical environment has been one of its aims as well as one of the problems. After the first peroneal stimulator was described, several electronic devices have been developed and applied (3). From their application and evaluation and from the research work which has been going on, some general requirements have emerged. Devices for patients should be simple and versatile and have high efficiency and reliability. They should be small and unobtrusive without long control and stimulation cables while on the power supply should be independent and totally safe. Patients should not be able to change possible individual presetting of stimulation parameters. As with research and clinically oriented stimulators, devices for personal use should include, in spite of their low cost, all recent discoveries. Orthotic devices could also be used therapeutically. And last but not least, devices should be accepted by patients.

To a handicapped person a technical or an orthopaedic aid becomes an important acquisition if it is functional, harmless, aesthetically acceptable, easy to adjust, as well as inexpensive. It is therefore imperative for us to follow technical progress, to develop aids, perfect them and create new ones more easily available to patients. All of them should of course be properly evaluated before being presented to patients as orthoses or therapeutic aids.

The first official evaluation, published at an international meeting in Portorož in 1971, confirmed the practical value of FES on 412 observed hemiplegics over 4 years (2). A version of the first aid improved in 1974 is still being produced today under the name FEPA PO-10. Then and some years later we thought an electrical stimulator would be needed as a permanent aid only. But the picture than changed in favour of a great number of therapeutic applications, diminishing number of electrical stimulators applied as orthoses. In recent years we have discovered the very great therapeutic value of FES in initial gait training since we stimulate up to 80 % of all hospitalized and out-patients (admissions per year 200-220 patients). To achieve greater number of applicable permanent gait orthoses new generations have been developed and have been analyzed according to the determined criteria:
acceptance by patients, functionality, reliability, aesthetic design.

The stimulators became smaller, so that Microfes was designed as small as possible (miniaturization), more aesthetic and more convenient for attachment under the knee, with a smaller number of cables. The functionality has been improved by changes in parameters, with better adjustable WDR sequences. We noticed possibilities for stabilizing an unstable knee. Finally implantable system as the third generation has been developed and applied to 35 patients (5).

Based on the experience of 2500 patients complex comparative analysis of three different FES devices has been done. The aim of this research was to find out the best way of brining patients' requirements into line with the possibilities open to designers and producers.

METHODOLOGY

According to the problem a holistic system approach seems to be favourable and acceptable from different points of view: technology, indications, patient acceptance etc. Some of these items are interrelated but frequently mutually opposed. Therefore an interdisciplinary team approach was neccessary to provide evaluation under the axioms (assumptions) as follows:

- The orthosis has to permit the patient to perform activities which would not be possible without it and which the patient wishes to perform.
- The device must serve a real need. Applying an unnecessary apparatus can be as dangerous as not applying a necessary apparatus.
- Functions which cannot be achieved by bracing should be avoided. An orthosis is not a fixed solution to the problem; it may be applied during a period of recovery meaningfully for months or years, yet one day be correctly discarded by both patient and physician.
- The patient's acceptance of the orthosis, including apearance and self application, means, that the patient is much more likely to accept a cosmetically attractive orthosis.

TECHNICAL SYSTEM DESCRIPTION

The system known as the PO 10 Ljubljana Functional Peroneal Electrical Brace, is intended for functional correction of gait in paretic patients and consists of: stimulator, electrode cable, electrodes, elastic knee support and shoe insole with a microswitch (Fig.1).

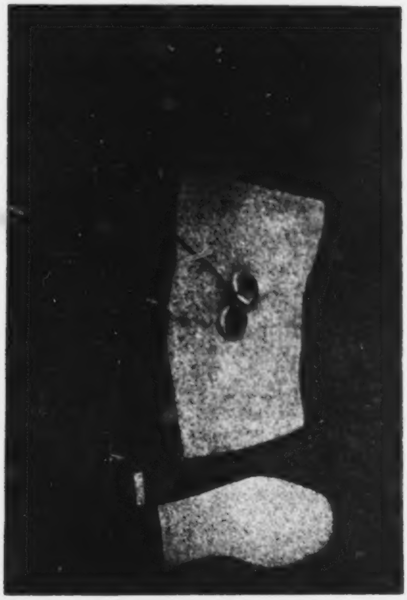

FIG. 1

Electronic parts of the stimulator are placed in a specially designed housing appropriate for this type of patient. Only those elements used to change parameters of stimulation impulses which are set in everyday use may be accessible: they can be manipulated by the disabled person him/herself.

On the front side there is a control of quite suitable size for switching on the stimulator, which is used for setting the output stimulation voltage. The control has a scale with digits from 1 to 5. Voltage stimulation increases if the control is turned clockwise and is practically independent of the load.

The underknee peroneal stimulator MICROFES (Fig. 2) is an orthotic and therapeutic electronic aid for patients with upper motor neuron lesions.

The stimulator is attached immediately under the knee. The stimulator and surface electrodes are held in place by an elastic knee support.

Requiring practically no energy, the CMOS control circuitry and pulse generator are permanently connected to the battery. The energy consuming part of the whole circuitry is turned on and off by the input control signal only when necessary, which extends the battery life significantly. An on-off switch is thus no longer necessary, patients only choosing the stimulation intensity.

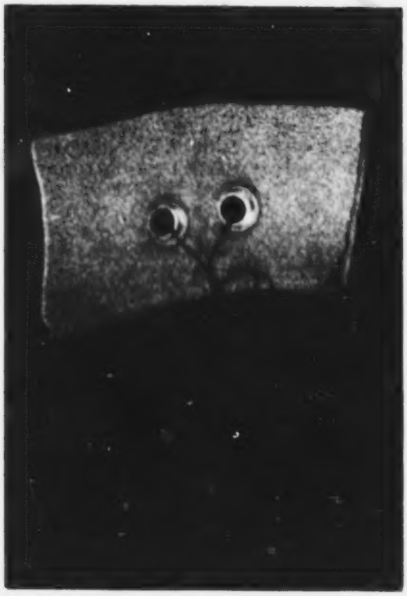

FIG. 2

The stimulating electrical pulse train is triggered by lifting the heel of the impaired leg during the push-off phase and is turned off by the landing of the heel in the initial stance phase of the gait, thus providing fully WDR stimulation. The stimulator switches off by itself after 3 seconds in the absence of heel contact, preventing continuous stimulation. An adjustable initial delay of stimulation up to 350 ms after lifting the heel allows at least passive push-off movement at the beginning of the swing phase of gait. It also ensures that lifting the heel slightly without it being the beginning of the swing phase does not produce stimulation. The other delay after the heel contact with the support (100 ms) allows stimulation in the initial stance phase to reduce the impact of the leg with the ground and to prevent foot slap.

IPPO implantable peroneal stimulator is shown in Fig. 3. It consists of a heel switch which synchronizes the stimulation with the patient's gait, control unit with electronic circuitry that produces stimulation pulses and bursts of RF energy which are transmitted via the antenna to the implant. The dimensions of the control unit are 6 x 4.5 cm and patients can wear it on suspension belt under the knee.

The surgical procedure of implantation (20 - 30 min) is short and simple and carried out under local anaesthesia. A short (3 - 5 cm) incision is performed to expose the nerve and to position the implant next to it.

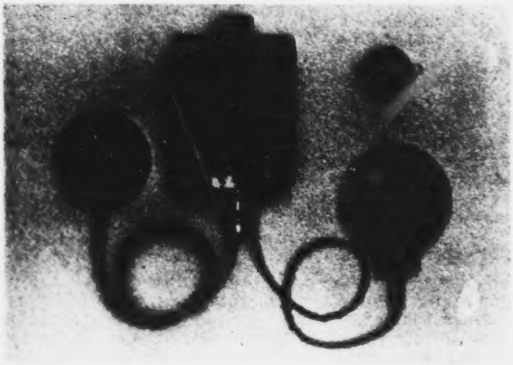

FIG. 3

Summarised technical characteristics of analyzed stimulators are shown in Table 1.

TABLE 1

	FEPA 10 (surface)	MICROFES (surface)	IPPO (implant)
Amplitude	10-60 V	10-130 V	7 V(2cm)
Frequency	25-50 Hz	25 Hz	33 Hz
Pulse width	0.5 ms	0.15 ms	0.1-0.5 ms
Train duration	0.3-2 s	WRD, max 3s	WRD, max 4s
Triggering	heel switch	heel switch	heel switch
Delay after Horr	none	0-0.35 s	0-0.3 s
Delay after Hox	none	0.15 s	none
Battery	9 V	1.5 V	1.5 V
Size	112x73x38 mm	65x45x18 mm	65x45x18 mm
Weight	190 g	65 g	65 g
Place	belt	knee	knee

(WRD - walking rate dependent)

RESULTS

Characteristics of patients:
From a group of 2,500 patients (2-3 million population) treated during the last 10 years a representative randomly chosen sample of 1000 patients was analyzed (450 women, 550 men from 21 - 63 years of age). Due to the main pathology (stroke, brain injury, operated tumors, high spinal cord lesion, multiple sclerosis) impairments on average of 4 - 20 months after primary treatment were found as follows: left hemiplegia (400 patients), right hemiplegia (550 patients), right + left hemiplegia (50 patients).

- FEPA 10 (n = 670). Permanent orthosis for 20 % of patients (2 - 4 hours daily use), therapy for 4 - 6 weeks (20 min per day) for 80 % of patients.
- Microfes (n = 120). Permanent orthosis for 80 % patients (4 - 6 hours daily use), therapy for 20 % of patients (20 minutes daily use).
- IPPO (n = 35). Evaluation started 5 years ago, permanent use up to 10 hours per day for 96 % of patients.
- Other (n = 75). Other types of ES, plastic and metal peroneal brace.

We achieved mobility in a relatively short time using electrical stimulation. It is possible to reduce the period of hospitalization, which is indicated by the 25 % greater monthly frequency in admission and discharge over the last 6 - 7 years.

CONCLUSION

In spite of the improvement of the 1st generation of electrical stimulators analyzed, encumbrance is being partialy continued. The exeption is the IPPO, which is very simple to use, reliable and has been most often requested by patients in spite of 3 reimplantations of dislocated implants (1). The lessened tonic component of spastic gastrocnemius due to chronic electrical stimulation during walking is the most objective result of constant daily use (4).

Objective criteria have given us very important and useful information on the orthotic quality of electric devices, but the most important criterion seems to be acceptance by disabled people.

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COMMAND CHANNELS FOR UPPER LIMB NEURAL PROSTHESES

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Abstract

We report on an experimental method to investigate command channels for upper limb neural prostheses which restore grasp by electrical stimulation of forearm muscles. We have developed a hardware simulator where potential command channels on able-bodied and SCI subjects are instrumented. The subjects control those channels to perform simulated tasks by manipulating animated hands appearing on a computer graphics display. This paper describes the hardware simulator and reports on a set of experiments whose goal was to determine the effects of the time delays caused by the graphics computations.

Introduction

The goal of this work is to improve the functional capability of quadriplegics outfitted with an upper limb neural prostheses, a device which uses electrical stimulation of paralyzed muscles to return grasp function. In particular, we are interested in the command channel through which the user manipulates the prosthesis, an integral part of the device which must be considered when evaluating overall performance. Our objective is to quantitatively evaluate current and future command channels for upper limb neural prostheses using an experimental model which closely simulates a complete neural prosthesis system.

Background

There are many command channels which could potentially be used to control hand grasp neural prostheses, including voice, head or eye motion, or the electrical activity (EMG) of muscles. The common choice of command channel for hand grasp, however, is shoulder motion (1). In a typical system, elevation and depression of the shoulder proportionally controls grasp force by dictating the level of stimulation activation of flexor or flexor and extensor forearm muscles. Shoulder motion is a good choice because most C5-C6 quadriplegics lose the ability to grasp but retain good control over shoulder motion. Shoulder motion is also relatively easy to monitor and two degree-of-freedom transducers have been designed which can be concealed under clothing (2).

Shoulder motion has been used with success in clinical systems but its full potential for commanding complex grasp functions is not known. One disadvantage of this channel is that the shoulder is being asked to perform two potentially conflicting functions; moving the arm and thus the hand and opening and closing the hand. This is not a problem in unilateral neural prostheses where the contralateral shoulder is used for the command channel. If one were to implement a bilateral neural prosthesis, however, these conflicting functions might make it impossible to achieve fine control over bilateral grasping motions such as passing objects from one hand to the other. Other command channels, such as voice control, might be more appropriate in this case.

There are few quantitative studies of command channels. Vodovnik and Rebersek (3) looked at the information content in EMG signals, in shoulder position, and in shoulder force and concluded that shoulder position was superior. That study was limited to examining subjects ability to maintain discrete signal levels, a test whose results are difficult to extrapolate to how well subjects would perform on functional tasks. In addition, recent advances in EMG processing necessitate a reexamination of EMG as a command channel. A recent study by Johnson and Peckham (4) examined shoulder motion in more detail looking at range of motion, ability to control two independent degrees of freedom during fast and slow motions, and ability to maintain constant shoulder positions.

Our Approach

Our approach in investigating command channels is to isolate them from the rest of a neural prostheses through the use of a hardware simulator which is described in detail below. Potential command channels are monitored and used to drive animated hands performing simulated tasks on a computer graphics display. This approach has several advantages. First, we can concentrate on just the command channel without concern for factors such as surface electrode motion, issues which are of vital importance for a complete neural prosthesis but which distract one from effects due to the command channel. Second, we can create realistic simulated tasks for performance evaluations. Third, we can easily evaluate alternate command channels and also how best to use a particular channel, including issues such as whether an input command should be proportional to hand position, velocity, force, or some combination of these such as stiffness or damping. Finally our simulator allows us to conduct experiments using able-bodied or spinal cord injured subjects with equal ease.

In this paper we give a detailed description of the hardware simulator and describe some preliminary experiments using able-bodied subjects. These experiments were designed to help us decide how much time-delay we can tolerate in the graphics computations and still maintain accurate simulations.

Hardware Simulator

Overview

The hardware simulator, illustrated in Fig. 1, is used to investigate command channel interface schemes.

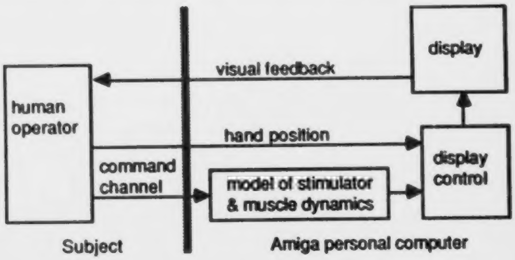

Figure 1 Hardware simulator block diagram.

A subject performs simulated grasping tasks by positioning his or her own hand to translate the animated hand which appears on the graphics screen. The grasping motion of the animated hand is driven by a controller algorithm, running on the computer, which includes a model of the dynamics of electrically stimulated muscle and whose input comes from transducers monitoring the appropriate command channel, such as shoulder motion, derived from the subject. By watching the graphics display, the subject has continual visual feedback of the task as would be the case for an actual neural prostheses.

Hardware

For this real-time graphic animation environment, the need for fast graphics processing is obvious. We chose the Commadore Amiga personal computer because of its sophisticated graphics capabilities and low cost. The Amiga mouse provides a convenient method for locating an object in 2-D and in our simulator is splinted to the subject's hand to transduce hand position. Two mice can be used to simultaneously locate both hands. We used the standard 13" Amiga color monitor for the graphics display. We designed and built an eight channel analog data acquisition system which enables the Amiga to receive signals from the analog command channel transducers mounted on the subject.

Software

Because the simulation is implemented in software, we have great flexibility in changing parameters of controller algorithms, dynamics of the stimulated muscles, and types of simulated tasks. The software for data acquisition, dynamics simulation and display graphics is written in C and we carefully optimized the code to minimize computation delays, making use of integer arithmetic and look-up tables where possible. The graphics software makes extensive use of sprites, hardware controlled graphics elements, to provide fast, accurate movements of objects on the display. Simulated open and closed loop neural prosthesis controller strategies can be readily tested and manipulated objects can be varied in their size, shape, weight, and stiffness.

Tasks

Our choice of simulated grasping tasks was dictated by the desire to mimic real tasks as closely as possible. To help in choosing tasks, we conducted an informal study of how able-bodied subjects use grasp in activities of daily living (ADL). The results showed that grasping tasks mostly fall into two main categories. Tasks require either a simple position, grasp, and hold (PGH) type of grasp as would be used in drinking, eating, washing or writing or require complex manipulation such as opening a can or buttoning a shirt. Palmer and lateral grasps dominate all tasks. Because of the applicability of PGH grasp to many ADL tasks, we chose to implement them in our simulator. We limited the model to palmer prehension because it is easy to implement in 2-D graphics.

The simulator has both one and two handed tasks. The one hand task, illustrated in Fig. 2a, requires the manipulation of a single object which could be a drinking cup.

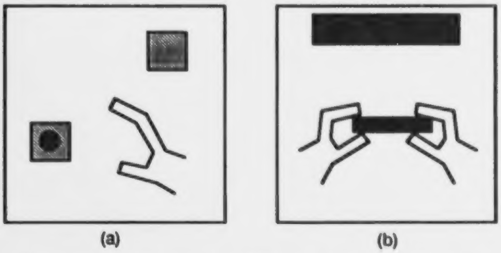
(a) (b)

Figure 2 Animation graphics for two simulated tasks. **(a)** One hand object grasping task. **(b)** Two hand manipulation task.

When the object appears on one of the two tables, the subject moves the animated hand from the start position, grasps the object, and moves it to the second table. After releasing the object, the subject returns to the start position to complete the trial. At the end of a successful trial the table without the object appears in a new location and the process is repeated. The subject's performance on the task is measured by the time it takes to complete a set number of trials with penalties incurred if the object is dropped while traveling from table to table.

The two hand task is similar except that an interaction between hands is required (Fig. 2b). At the start of a trial, the object, which could be a pencil, is on the table and both of the animated hands are in the start position. The subject must grasp the object with one hand, move it off the table, pass it between his two hands a set number of times, return the object to the table, and finally return both hands to the start position.

Shoulder Motion Transducer

We designed and built a lab-based experimental apparatus for measuring both elevation-depression and protraction-retraction of the shoulder. The measuremant system employs two joysticks mounted on either side of a chair. The joystick arms are mounted to the top of the subject's shoulder creating a two-axis position sensor on each side and the signals can be used in any combination to construct a command input to the simulation.

Limitations

The limitations of the simulator are evident. Its primary shortcoming is that tasks are limited to two-dimensional simulations. One could develop a set of 3-D graphics for more complex tasks but the display computation time would become prohibitive. A second limitation is that many of the details required to present an accurate simulation of a task are simply too complex to incorporate in the simulation. Examples include sophisticated muscle dynamics or the detailed contact interactions which the fine behavior of a grasping task. A third limitation is that rather than manipulating their own hand, subjects are using their hands and shoulders to drive the simulations and the natural relation between proprioceptive and visual feedback is not present in the simulations. This is most evident when performing simple simulated hand position tracking tasks which are easier to do using the real hand.

Time-Delay Tracking Experiments

Objective

Drawing real-time graphics of any complexity takes time, even with the powerful graphics capabilities of the Amiga. One is obligated, therefore, to determine whether the time-delay introduced by the graphics computations leads to significant performance degradations on the simulated tasks. This in turn will determine the permissable complexity of the simulated model and task graphics. For example, one could generate realistic animated simulations using 3-D color shaded images of hands and objects but performance on the simulated tasks would be dominated by operating a system with delays of five or more seconds required to generate the images.

The objective of this initial set of experiments was to determine how subjects perform when operating systems with time delays in the forward path. By plotting performance versus time delay one can make intelligent design choices about what graphics to implement. Others have investigated tracking performance in the presence of time delays, but we felt it important to do our own studies using our hardware simulator. In the experiments described below, we investigated discrete target acquisition tasks using hand motion.

Methods

Subjects performed a discrete tracking task using the Amiga mouse to control a crosshair cursor on the screen. At the start of the task, a box, slightly larger than the cursor, appeared in a random location on the screen and the subject moved the cursor into the box. When the cusor had stayed completely within the box for 0.4 seconds, the box moved to a new random location and the subject again moved the cursor into the box. A trial consisted of 50 such moves with performance measured by the time to complete the task. A time delay ranging from 40 to 440 milliseconds in steps of 40 msec was inserted between the motion of the mouse and the motion of the cursor on the screen. Ten subjects each performed a complete set of ten tasks, one per time delay, with the time delays presented in random order and not told to the subject. The subjects were not able to jerk the mouse because of slippage in the mouse transducing mechanism, but this did not appear to be a serious limitation for these experiments.

Results

Performance times for each subject were normalized to To, the time to complete the task with a 40 msec delay, the shortest possible for our computer hardware and software. The combined results are displayed in Figure 3 which plots normalized task completion times averaged across all ten subjects as a function of time delay. To, the normalizing factor, averaged 78.2 seconds with a standard deviation of 8.0 seconds.

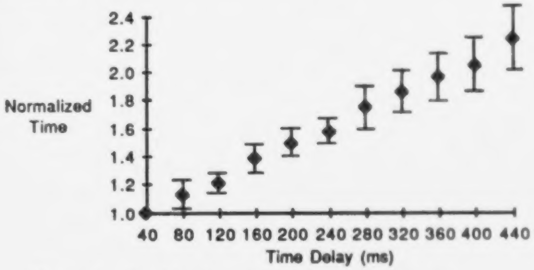

Figure 3 Combined time-delay experiment results. Dots indicate mean performance across all subjects, crossbars indicate standard deviations.

Discussion

That performance is affected by time delay is evident and expected. The relatively small standard deviations show that normalized performance is consistent across subjects. Other experiments, not reported here, show that repetitions within one subject are also consistent if that subject has had sufficient training on the simulator to overcome learning effects. This means that graphics computation delays will affect performance on the simulated tasks but in a predictable manner which will be roughly constant across all subjects. One surprising result was that the time-delay versus performance curve is approximately linear although subjects reported that doing the tests at the longer time delays required significantly more concentration than those at the shorter delays.

Presently, our graphics for the single hand grasping task sketched in Figure 2a takes 83 milliseconds to compute. In these tracking tests this delay results in a 13% average performance reduction over a 40 ms time delay, the shortest delay we could program on the Amiga. Although not ideal, we feel this 83 msec delay is an acceptable tradeoff for our simulator.

We plan on extending these preliminary time delay tests. We will add a continuous tracking test to our experiment and will test tracking both with the hand controlling the screen cursor via the mouse and with the screen cursor controlled by shoulder motion. We also plan to add concurrent mental load tests to determine how subject concentration on the task varies with time delay.

Conclusions

We feel that our hardware simulator is an effective means for evaluating command channels for upper limb neural prostheses. The primary advantage of using the simulator is that it isolates the evaluation of command channels from other components of a neural prosthesis. A long term objective would be to use the simulator as a prescription device to evaluate various command channel modalities on individual patients. Our initial efforts have concentrated on ensuring that the simulator is a sufficiently accurate representation of a real neural prostheses system. Next we will evaluate unilateral and bilateral shoulder motions with one and two degrees of freedom for each channel in both able-bodied and spinal cord injured subjects.

Acknowledgements

We would like to acknowledge the contribution of David Brancazio, an MIT undergraduate student, who designed and built the shoulder transducer hardware used in this work. This work is supported in part by the U.S. Department of Education, National Institute on Disabilities and Rehabilitation Research, Grant No. G008300074. The work was performed at MIT in the Eric P. and Evelyn E. Newman Laboratory for Biomechanics and Human Rehabilitation.

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THERAPEUTIC AND FUNCTIONAL STIMULATION OF ARM IN SPASTIC HEMIPARETIC PATIENTS - A FEASIBILITY STUDY

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ABSTRACT - The influence of arm swing movements on gait patterns was studied in healthy subjects and hemiparetic patients. Functional electrical stimulation was applied to emphasize the arm swing during walking in hemiparetic patients. As additional therapy in the early stage of rehabilitation therapeutical stimulation was introduced with the aim of spasticity relaxation in elbow muscles. The spasticity was tested with specially adapted pendulum test, the gait was estimated by foot-switch functions and velocity of center of gravity of the body, while the arm swing movements were measured by goniometers. The step length and push-off velocity were found to be the most sensitive parameters to arm swing movements in healthy subject. A reasonable improvement of gait utilizing functional electrical stimulation during walking was demonstrated. A slight decrease of spasticity in biceps muscle was found after regular use of therapeutic stimulation.

INTRODUCTION

Neurophysiological, kinesiological and biomechanical phenomena of arm swing during normal walking have been studied by many authors (1,2,3,4,5). According to these studies the arm swing during walking is an integral part of locomotion and it has a great influence on the esthetic view of gait. Beside this, the arm movements should have an influence on gait parameters also. In hemiplegic patients the arm swing movements, which are present in gait of healthy subject, are usually not possible due to spasticity and paresis. Two different patterns of arm position can be seen in these patients. In spastic ones the affected arm is flexed at the elbow. This flexion becomes stronger when patients are walking, particularly if they need a higher effort for walking. In the other ones the arm is flaccidly hanging down also during walking. At both patterns of arm position the posture of trunk is frequently changed, too. In the present study we tried to find out how this pattern can be improved by means of electrical stimulation, which gait parameters are the most sensitive to arm swing movements and which sequence and site of stimulation should be the most successful for arm swing movements during walking. Our study was oriented on both therapeutic and functional use of electrical stimulation of arm to achieve relaxation of spasticity and swinging of arm during walking. In the early phase of rehabilitation, walking was usually not possible and the arm muscles have been therefore stimulated only therapeutically to decrease the level of spasticity. Once the patients were able to perform walking with the help of leg muscle stimulation, additional channels were used for functional stimulation of arm swinging.

METHOD AND MATERIAL

For evaluation of therapeutic and functional improvement of arm position and swinging during walking we used two different measurement methods. With the first one we tested spasticity at the elbow joint muscles during period of therapeutic stimulation. When the patients were able to walk by means of electrical stimulation we introduced also the measurements of gait parameters simultaneously with the both sides arm goniograms.

Therapeutical stimulation and spasticity testing

This kind of stimulation was performed every day for three to four weeks time period. Alternating stimulation of triceps and biceps muscles were applied to patients for thirty minutes each day. The sequence of stimulation was 6 sec. on and 6 sec. off for triceps muscle while for the biceps it was 4 sec on and 8 sec off. The delay between triceps and biceps stimulation was set to zero, so that the delay between biceps stimulation and next triceps stimulation was 2 sec. The pulse width was 235 µs and the frequency of stimulation 33 Hz. A constant current stimulator was used with an amplitude setting from 30 to 40 mA. Spasticity in these two muscles was tested before therapeutic stimulation, in the middle of therapy and at the end of therapy. For testing of spasticity a modified pendulum test (6) was used. The elbow goniometer was attached to the arm together with EMG electrodes placed over the triceps and biceps muscles. A special sliding table in nearly vertical position was used to avoid friction between arm and trunk. The patient was sitting behind this table with the upper arm fixed on the table for 20° in retroflexion. During the pendulum test, the examiner grasped the forearm and brought it to a horizontal position, where the elbow joint was in 110° of flexion. The arm was than allowed to fall freely, while recording the elbow angle and EMG activity of both muscles. The data were first stored on magnetic tape recorder and than processed with a waveform analyzer DATA 6000.

Functional stimulation and gait measurements

For the functional evaluation of arm swing movements we used a simple kinematic gait measurement technique (7) to which we added four arm goniometric functions of elbow and shoulder of both sides. This goniometric system was able to measure only sagittal angles with an accuracy of few percents. With such a combination we were able to measure arm swing movements together with sixteen gait parameters including step length and velocity of center of gravity of the body. The complete system was first tested on healthy subjects. The purposes of these measurements were testing of reliability, comparison of arm swing movements with those in the literature and the investigation of the most sensitive gait parameters to the arm swing movements. The healthy subjects were walking at different cadences determined by metronon with normal swinging of arms and with arms fixed to the trunk by a belt. The measurements on patients were performed three times during the period of their rehabilitation of walking. This period lasted usually from one to four months, and the measurements were performed approximately once per month. Typical measurement consisted of a few gait sequences with and without stimulation of arm muscles. Inside one gait sequence fifteen to twenty steps of walking were measured. All data were stored and processed by HP 2100 computer

The selection of patients and stimulation sequences in walking

Fundamentally only patients with spastic paresis were chosen for this program although we tried stimulation of arm during walking also in some patients with flaccid paresis. The necessary number of stimulation channels were in these patients higher than in spastic ones, therefore we left off the stimulation of these patients.

Five hemiparetic patients with spastic paresis in arm muscles were included in kinesiological measurements. For each patient a separate stimulation program was determined depending on his arm swing deficit. In most cases the stimulated muscles were triceps brachii and biceps. These muscles are not the important ones for the arm swing in normal conditions, but for the patients, stimulation of these muscles is a reasonable solution because the elbow is often flexed excessively and the fixation of surface electrodes, which we used, on the shoulder muscles is very difficult. The stimulation sequence for triceps brachii was triggered at the moment of heel-off and for biceps at the moment of heel on by foot switch. In many cases only the stimulation of triceps brachii was sufficient, since the opposite movement was present due to spasticity in biceps muscle.

RESULTS

Spasticity testing

For the evaluation of spasticity we used two parameters. The first one was a relaxation ratio as it is described at goniogram of healthy subject in Fig. 1. The second one was average value of EMG activity in both muscles during the pendulousnes. This activity was first numerically integrated and then divided by time of integration. Ten pendulum tests were performed in each measurement. From these tests a mean value and standard deviation of average value of EMG was taken as final result.

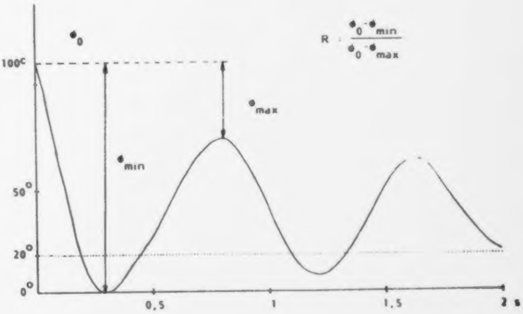

Fig. 1: Elbow goniogram of healthy subject

In Fig. 2 original records of one patient are shown which documents a spasticity state at the beginning of the therapy (Fig. 2a) and one month later (Fig. 2b). The numerical data of the same patient are given in Table I for the observed time of therapy.

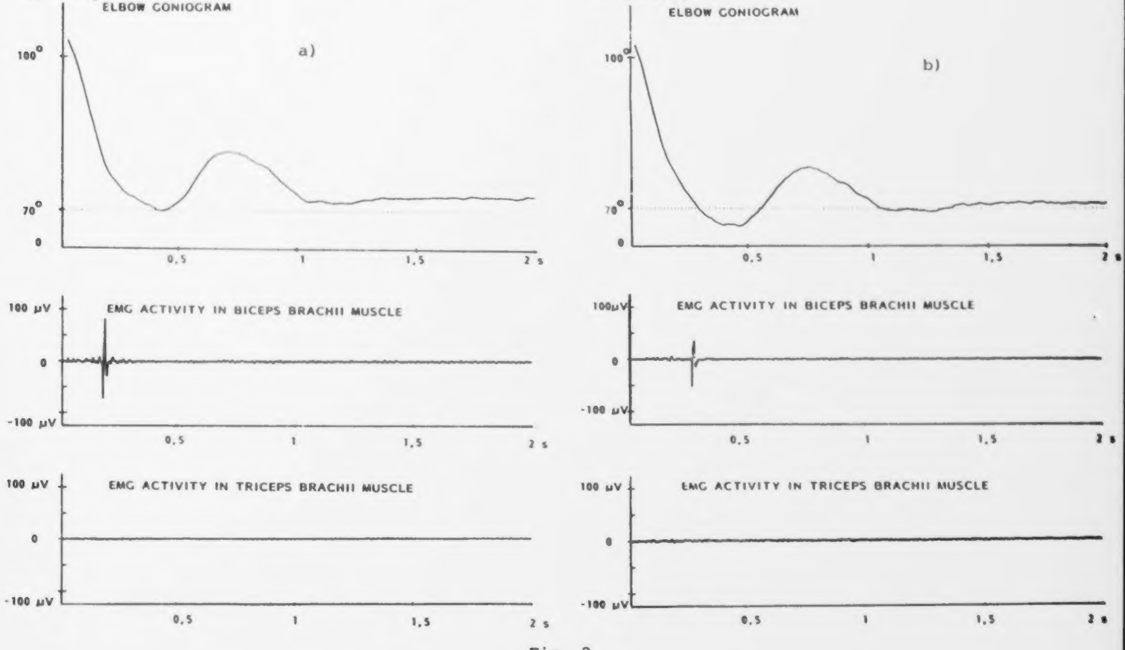

Fig. 2

TABLE I

Date of measurement	2.20.1987	3.6.1987	3.18.1987
EMG m.biceps brachii	(2.6±0.6)µV	(2.1±1.1)µV	(1.8±0.5)µV
EMG m.triceps brachii	(0.7±0.1)µV	(1.0±0.3)µV	(1.2±0.2)µV
Relaxation ratio	1.5±0.04	1.4±0.04	1.4±0.04

Gait measurements in healthy subjects

For the evaluation of gait patterns a clustering technique was used as described by Valenčič and Bajd (8). Together with this evaluation a sensitivity of parameters to arm swing movements were tested. The fixation of arms produced the most evident changes in step length and push-off velocity, which were from 71 cm to 63 cm and from 102.9 cm/s to 90.7 cm/s. These two parameters were found to be the most sensitive to arm swing movements, at cadences about 100 steps/min or more. Nearly 400 gait patterns of healthy subjects were included in statistical analysis of these two parameters which showed differences at significance level 0.005.

Gait measurements in hemiparetic patients

In patients we used preferably clustering technique to differentiate gait patterns obtained with stimulation and without it, since the differences in separate parameters were smaller and therefore not significant at such a high level (0.005). Therefore we compared only integrated estimation of the gait obtained by clustering technique. In Fig. 3 measurement results of averaged arm goniograms for one patient are shown. For the comparison the goniograms of the measurement without stimulation are noted with dashed lines and stimulation sequence is added. It is very interesting that for this particular patient with exessive elbow flexion, the muslce triceps brachii must be stimulated practically all the time to obtain movement of elbow joint. Such a situation is very usual for spastic types of patients. Through measurements of gait patterns we found important influence of arm swing stimulation on gait pattern. Always, when stimulation was used, the gait pattern was shifted to more normal ones. Relative differences were approximately 10-20%.

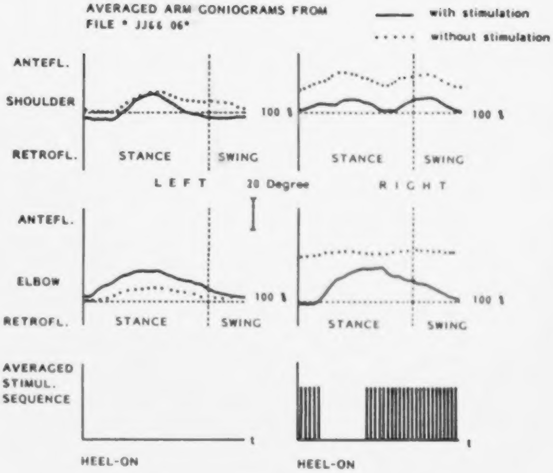

Fig.3:Averaged arm goniograms obtained in patient Š.J. with and without stimulation. Stimulated muscle was triceps brachii.

DISCUSSION

Our feasibility study has shown the importance of arm swing movements for walking of both, healthy subjects and hemiparetic patients. To our knowledge, no one except authors listed in references have studied the direct influence of arm swing on gait in healthy subject. Furthermore no data were collected from hemiplegic patients. Our study has demonstrated how important is the arm swing pattern for the gait of hemiplegic patient. We very often observed an improvement of arm goniograms also on the non-affected side (see Fig.3). It is interesting to mention that the useful sequence of stimulation of triceps muscle in spastic patients is very similar to that one, used for peroneus stimulation. Furthermore, if spasticity is not too strong exactly the same sequence would produce the best swinq movements. This means, that such a stimulation can be performed with the same channel for both peroneus and triceps muscle, which ideally simplify the equipment and stimulation procedure. With a therapeutic stimulation in the early phase of rehabilitation the spasticity can be decreased to a reasonable level (see Fig.2a,b) so that such simple stimulation is possible later, when patient is able to walk. Finally it should be mentioned, that in the routine rehabilitation procedure a much higher number of patients benefited from such stimulation while only five of them were included in the kinesiological study.

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ELECTROMYOGRAPHIC STUDY OF THE BACK STEP FOR DEVELOPMENT OF ELECTRICAL STIMULATION PATTERNS

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ABSTRACT

Electromyographic (EMG) activity of the trunk, hip and leg muscles was studied during slow stepping backwards in a normal subject. Muscle EMG activity was detected using surface electrodes and synchronized with different phases of the step using foot/floor contact sensors. Based on EMG activities of a normal subject, a basic stimulation pattern for stepping backward was developed and programmed into a 32-channel microprocessor-controlled stimulator. The stimulation pattern was used to induce backward walking in paraplegic subjects. The subjects had percutaneous intramuscular electrodes implanted in most major muscles controlling the hip, knee and ankle; surface electrodes were used for stimulation of muscles controlling the lateral movement and extension of the trunk. After some modification of the basic stimulation pattern, based on trial and error, the paraplegic subjects were able to step backward using a walker or parallel bars for support.

INTRODUCTION

Functional neuromuscular stimulation (FNS) has provided selected paraplegic subjects with the ability to climb and descend steps with support of one crutch and one rail (1), to walk with a walker (2) or crutches (3), and to step sideways (4). For the FNS system to be functional in activities of daily living it must also be capable of providing the subject with the ability to move around obstacles and to open doors. This often requires a step to the side or backward. A difficulty in developing stimulation patterns for various activities is determining which muscles to stimulate during different phases of the cycle and by how much to stimulate them. Considerable insight can be gained by analyzing the EMG activity in a normal subject performing specific tasks. In this report we present results of electromyographic activity during back step as determined by surface electrodes.

METHODS

We studied the activity of the trunk, hip and leg muscles during a back step using surface EMG electrodes with built-in preamplifiers placed over different muscles of a normal male subject. The EMG signals were amplified, band pass filtered (20HZ-2KHz) and recorded on a fiber optics chart recorder (Honeywell model 1858 CRT Visicorder). Because the number of electrodes was limited, two series of tests were conducted, each using seven electrodes. In the first series, electrodes were placed over the surface of the left and right erector spinae, the right gluteus medius, semitendinosus, vastus lateralis, medial gastrocnemius and tibialis anterior. In the second series electrodes were placed over the left and right gluteus medius, left semitendinosus, rectus femoris, vastus lateralis, medial gastrocnemius and tibialis anterior. Preliminary tests were conducted separately to record the activity of the quadratus lumborum and rectus abdominis. Hip flexors were not considered since their EMG signals are not readily detected by surface mounted electrodes. The muscles included in this study were the ones currently available for stimulation in our FNS system which has been designed to provide paraplegic subjects with the ability to perform functional tasks. Our FNS system uses percutaneous intramuscular electrode for stimulation of most major muscles controlling hip, knee and ankle at stimulation parameters previously described (1). Surface electrodes are used for transcutaneous stimulation of muscles controlling lateral bending and extension of the trunk.

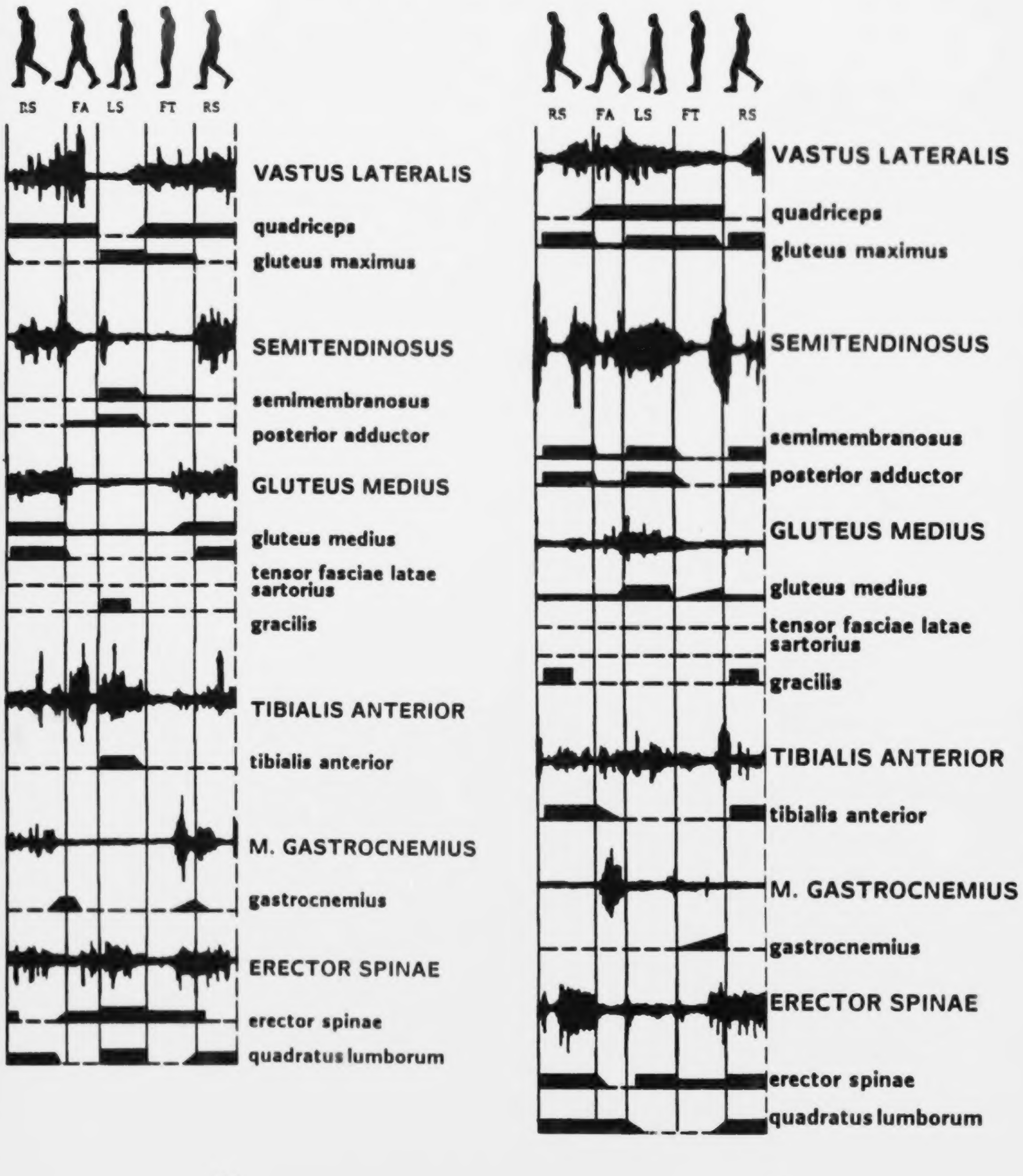
Foot/floor contacts from the heel, medial and lateral aspect of the feet and force plate data were recorded on a MINC 11/23 (Digital Equipment Corp.) and synchronized with the EMG recordings using a trigger pulse. In the experiment the subject stood in front of two force plates (AMTI Model ORG-5-6) and took a series of back steps over the plates. Trials were done with both right and left back steps on different days to ensure repeatibility of the data. The timing of the steps was regulated with a metronome. The back step cycle was divided into four phases. The cycle was initiated from a double support stance phase with the feet together (FT). The next phase was a backward swing of the right leg (RS) ending in a double support phase with feet apart (FA). Then the left leg was brought back (LS) ending in the feet together stance. In this respect, the back step differed from normal backward gait (5) and was therefore not a symmetrical cycle. Based on the muscle activity in the normal subject, as recorded by the surface EMG, a basic stimulation pattern was developed and programmed into a 32-channel portable stimulator. The stimulation pattern for the muscles not tested for EMG activity was determined based on our experience in walking with electrically stimulated muscles (1,2,4). The basic pattern was tested on a paraplegic subject and modified by trial and error.

RESULTS

The normal subject stepped backward at an approximate speed of .36m/sec, with step length of about 60 cm. The mean times of the different phases were .41 sec for the FT phase, .48 sec for the RS, .29 sec for the FA and .47 sec for the LS phase. The right swing phase most often began from lateral right foot contact in the FT phase and ended with lateral contact in the FA phase. The left swing began from a left heel contact and ended with a lateral contact in the FT phase. The left swing was initiated with the right foot in either toe or foot flat (lateral, medial and heel) contact.

In the following, results are shown for only the right back step as we found that the results for the left back step were symmetrical. We found that the EMG signals were very repeatable from trial to trial on different days, both in terms of the muscles that were active and their timings. Figures 1a and 1b show the raw EMG signals indicating the activity of the various muscles tested from two representative trials. Included in the figures is a stimulation pattern, developed from the EMG signals, which enabled paraplegic subjects to

EMG of Back Step



(a) (b)

Figure 1: EMG activity (upper case) and muscle stimulation patterns developed from them (lower case) for muscles on the left (a) and right (b) side of the body during the back step.

step backward with the aid of FNS and parallel bars or a walker for balance.

The EMG data indicate that the right tibialis anterior was most active at the end of the FT stance and the beginning of the RS. Often activity was observed near the end of the LS and the beginning of the FT phases. The left tibialis anterior was most active during the latter part of the RS phase and at the right toe-on at the beginning of the FA stance. Activity of the left tibialis anterior was also observed during the LS phase.

The right medial gastrocnemius was most active during the FA stance phase with occasional activity during the LS phase. Left medial gastrocnemius activity began at the end of the FT stance and continued part way into the RS phase.

The right vastus lateralis was active throughout the right stance including the FA, LS and FT phases. The activity diminished during the first half of the RS phase. The left vastus lateralis was active during the left stance and quiet during most of the LS phase. The left rectus femoris exhibited activity similar to the left vastus lateralis.

The right semitendinosus was most active during the LS and at the beginning and the end of the RS phase. Often diminished activity occurred during the RS and FA phases. The left semitendinosus showed most activity during the RS phase.

The activity of right gluteus medius began in the FA phase and lasted through the LS, part way into the FT phase. Activity of the left gluteus medius started in the FT phase and continued during the RS phase. Thus, the activity of the gluteus medius alternated between left and right sides.

The right erector spinae was active throughout the RS phase, beginning at the end of the FT phase and ending in the FA phase. Similarly the left erector spinae was active during the LS phase, starting during the FA phase and ending in the FT phase. This muscle was also active during the right swing.

The right quadratus lumborum was most active during the FA and LS phases, while the left quadratus lumborum was most active during the FT and RS phases. The rectus abdominis on either side showed no considerable activity throughout the back step.

DISCUSSION

It is difficult to explain the precise role of each muscle during a complete back step cycle. However, some reasonable predictions can be made based on the gross motions that occurred.

At the beginning of right swing, the left gastrocnemius provided the initial backward motion for the back step. Once backward motion started, the left tibialis anterior appeared to provide a push-off in a reverse manner to the push-off provided by the ankle plantar flexors during forward walking. This is consistent with results in (5). At the same time, the right tibialis anterior was active, allowing the foot to clear the floor, while the left gluteus medius and right erector spinae raised the right side of the pelvis. The right semitendinosus aided in the backward swing of the right leg. The activity of other hip extensors was not recorded, but it is probable that they also assisted in bringing the right leg back and regulating the length of the step. During the RS phase, the left and right erector spinae were active, giving stability to the upper body while the left semitendinosus helped to support the hip. The right gastrocnemius was active during the FA phase to provide for a smooth transition from the RS to the LS phase. During the left swing phase, the left tibialis anterior was active allowing the foot to clear the floor while the right gluteus medius and left erector spinae raised the left side of the pelvis. The right semitendinosus kept the hip extended probably with help from other hip extensors to complete the cycle.

Although the final stimulation pattern differed somewhat from the initial pattern developed from the EMG data, we found that the EMG data provided a good starting point for creating the backstep stimulation pattern. It was important for the paraplegic subject to stand erect during stepping backward because leaning forward tended to lengthen the step making it more difficult to transfer the weight to the leading leg. Subjects found the back step more difficult than forward walking because of lack of visual feedback on the position of foot placement.

ACKNOWLEDGEMENTS

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DESIGN OF A QUICKLY-ASSEMBLED, LIGHT-WEIGHT LEG ORTHOSIS FOR FES ASSISTED PARAPLEGIC MOBILITY

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ABSTRACT

A leg orthosis, which has a special knee joint that can be locked in any position, has been designed that can be quickly donned and doffed by paraplegics. It is intended for use with functional neuromuscular stimulation to enable them to access places with narrow corridors and steps. It also will provide for unassisted standing up from the wheelchair to reach objects normally out of reach. The design simplifies and improves on a "Self-Fitting Modular Orthosis" developed in Belgrade, Yugoslavia. The new orthosis is named the Utah Quick-Assembly Light Leg Orthosis (UQALLO).

INTRODUCTION AND BACKGROUND

Most paraplegics rely primarily on the wheelchair for mobility and access in the home and at work. Although most paraplegics are supplied with, and trained to walk with, ankle-knee orthoses and crutches, these are rarely used for a variety of reasons. Some of these are: (1) difficulty in putting the orthoses on and off, (2) precarious standing up and sitting down transition with locked knees unless assisted by others, (3) the expense of custom refitting of the orthoses as leg muscles atrophy, (4) inadequate human engineering in terms of attractive looks, light weight, and transportability as part of the wheelchair, and (5) the current locked-knee orthoses are very difficult to use in uneven terrain or where steps are encountered.

Significant progress has been made towards alternate methods of ambulation for paraplegics involving electrical stimulation of paralyzed muscles. Numerous workers (1-6) have used various approaches to reestablish reciprocating gait in paraplegics. Several research groups (1,3) have made progress towards implantable systems, however, based on the pace of advances over the last 20 years it may easily take 10 years or longer before such systems reach widespread clinical application.
In the near term (3 to 5 years) technically and clinically simpler, externally applied stimulation combined with a knee-ankle orthoses may fill the gap. Petrofsky et al (5) and Schwirtlich and Popovic (6) have used a combination of orthoses and electrical stimulation of a limited number of muscles to demonstrate the feasibility of standing up and walking. The number of stimulation channels can be minimized by use of a knee-ankle orthoses which essentially confines the motion of the lower legs to hip movement, knee extension and flexion and ankle dorsiflexion and extension (5). The orthosis devised by the Belgrade group (6) called a Self-Fitting Modular Orthosis (SFMO) has a particular advantage in that it can be attached or detached while sitting in the wheelchair. The orthosis is fitted to the outside of tight-fitting pants. Among its disadvantages are that the parts are not available commercially and custom machining the relatively complex parts is difficult and expensive. Furthermore the knee-joint locks only in the extended position. These disadvantages are eliminated with a new design.

DESIGN APPROACH

The Utah Quick-Assembly Light Leg Orthosis (UQALLO) is intended as part of a hybrid system using electrical stimulation of the quadriceps muscles to assist paraplegics to stand up from the wheelchair and walk with crutches and a reciprocating gait. The orthosis is designed to provide lateral stability to the knee and ankle, and will prevent collapse at the knee if the muscle activation fails or is inadequate to maintain the required torque at the knee-joint. It will carry significant axial loads under abnormal failure modes. Normally the axial loads will be borne by the bones.

Each leg of UQALLO consists of 8 components (figure 1): shoe, heel pin, knee joint, hip cap, two tibial tubes, and two femoral tubes. Shoes with heels are fitted with key-lock heel plates that accept the mating stainless steel pin on the heel component. Two stainless steel pins protrude from the top surface of the machined aluminum heel component which fit inside the tibial tubes. Both the tibial and femoral tubes are aluminum tent poles. The knee joint has two holes drilled in each end that the tent poles plug into. The proximal ends of the femoral tubes plug into two holes in the aluminum hip cap.

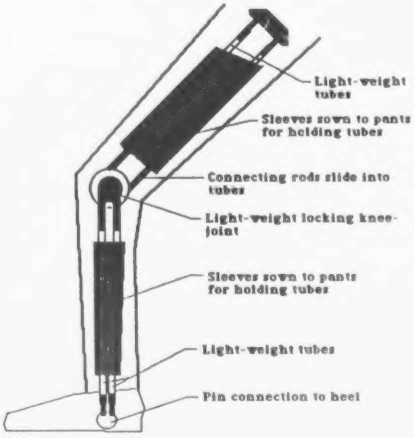

Light-weight tubes
Sleeves sown to pants for holding tubes
Connecting rods slide into tubes
Light-weight locking knee-joint
Sleeves sown to pants for holding tubes
Light-weight tubes
Pin connection to heel

Figure 1. Utah Quick-Assembly Light Leg Orthosis (UQALLO) showing attachment to pantleg and assembled parts.

UQALLO acquires its "self-fitting" attributes by using the modified tight fitting blue jeans of the Belgrade Orthosis. Jeans provide a comfortable, fashionable garment and, similar to the stressed skin design of airplanes, provide a lightweight, flexible web to hold the framework together. Velcro straps are added to the slit pants near the ankle to provide a snug fit and reduce relative motion between the leg and the orthosis. At the hip of the pants, a velcro flap covers a pocket which holds the hip cap of the orthosis in place. The length of the tubes are cut to fit the length of the leg. Note that tubes are designed to slip easily in and out on the pins at the heel and the holes at the knee joint of the orthosis. The assembly stays together by limiting the amount of extension between the hip pocket and the heel insert.

Design of Orthotic Knee Joint

Design of the components is relatively simple with the exception of the knee joint. The design specifications for the knee joint orthosis are given in Table 1.

Table 1. Design Specifications for the Electrically Locking Knee-Joint

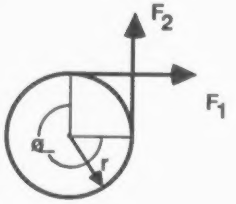
1. Light weight (< 250 gm. or 1/2 lb)
2. Size ≤ 10x10 cm with width < 2 cm
3. Withstand up to 200 N-m torque when locked.
4. Lock in any position.
5. Allow for electrical operation of brake.
6. No sharp edges, sheering or pinching action at all angles.
7. Cosmetically attractive and smooth

The relatively small size of the orthotic knee joint and the large torque requirement poses a significant challenge. For example a drum brake design with a 2.5 cm radius would require a net tangential friction force at the brake-shoe/drum interface of 8000 N (1800 lb). Assuming a friction coefficient of 0.5, this translates into a need to generate a 16000 N (3600 lb) normal force between the brake-shoe and drum. Levers or mechanisms that could generate such forces could not readily fit into the allowable space of the knee joint. Interlocking teeth or pins were possible alternatives for generating such large forces. However, such designs were judged to be complex to machine and would cause chatter or "jerky" breaking action when activated in a mode to stop an undesired movement.

The solution that was devised, uses a phenomenon well known to sailors, who manage to exert many tons of force on large ships by simply wrapping a rope several times around a drum and exerting low tension on the end of the rope. The mechanical advantage of such a drum and cable system (figure 2) is expressed in equation 1, where F_1 is the smaller force applied to one end of a flexible cable, F_2 is the larger force, μ is the friction coefficient between the cable and the drum, and ø is the angle of contact of the rope with the drum in radians. The net torque on the drum of radius r exerted by the cable is given by equation 2. Substituting equation 1 for F_2 in equation 2 results in an expression relating the force F_1 to the net torque T (equation 3). Equation 3 is used to estimate design parameters for a knee orthosis brake based on the cable and drum concept.

Prototype Fabrication

A first prototype of the knee orthosis has been constructed as shown in figure 3. The drum has a radius of 2.5 cm. The cable is a seven-by-seven strand stainless steel wire. It is wrapped 1 and 3/4 times around the drum (ø= 3.5π radians) One end of the cable is attached firmly to the case. The other end, which carries the lower force is attached to a small lever. The lever is spring loaded so that it applies a braking force, F_1, of 40 N to the cable - resulting in a normally locked joint. The lever is presently released by a hand brake mechanism as used for bicycles. The coefficient of friction between the cable and aluminum was measured at μ = to 0.3. Using equation 1, the calculated force gain factor is 27. Measurements of the torque required for slippage at the joint of the prototype indicate a factor of 30, which is within the expected error.



$$F_2 = F_1 e^{\mu \phi} \qquad (1)$$

$$T = (F_2 - F_1) r \qquad (2)$$

$$T = F_1 (e^{\mu \phi} - 1) r \qquad (3)$$

Figure 2. Drum and cable brake system and governing equations used for design of the knee-joint brake.

DISCUSSION AND CONCLUSIONS

A knee-joint orthosis has been designed based on a drum and cable brake system. Tests of a prototype knee-joint indicate that the design equation 3 can be used to estimate the torque for slippage of the brake system. The prototype drum has a radius of 2.5 cm and a $\mu ø$ factor of 3.3. Given a required torque of 200 N-m, Equation 3 can be used to calculate the required force, F_1. This force amounts to 306 N or approximately 70 lbs. The spring loaded lever arm (see figure 3) has a mechanical advantage of approximately 7, so that the spring needs to exert 44 N (10 lbs) of force. This is also the force required to release the brake either by mechanical means or by an electric actuator. We plan to significantly reduce the locking and unlocking force, F_1, by increasing the friction coefficient between the drum and the cable. Since μ appears in the exponent of equations 1 and 3, an increase of the friction coefficient from 0.3 to 0.5 will increase the mechanical advantage from a factor of 27 to 244. This in turn will reduce the required force at the lever by a factor of 9 to approximately 5 N (1.1 lbs). Forces in this range will be easy to generate manually or by electric actuation.

The prototype knee joint will be modified to increase the mechanical advantage to a range of 200. Thereafter the integrated orthosis system will be tested for torque capability and structural integrity under simulated body loads.

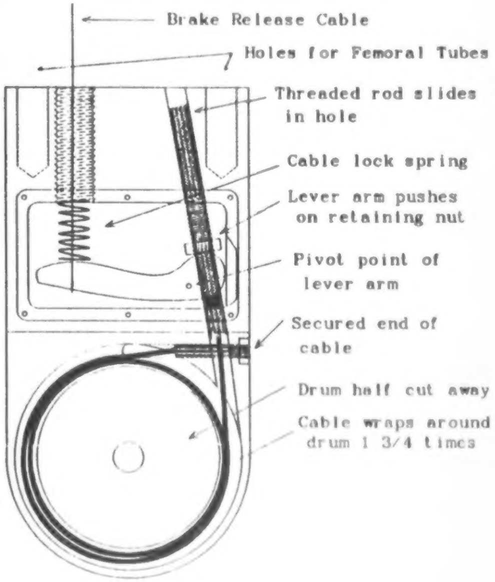

Brake Release Cable
Holes for Femoral Tubes
Threaded rod slides in hole
Cable lock spring
Lever arm pushes on retaining nut
Pivot point of lever arm
Secured end of cable
Drum half cut away
Cable wraps around drum 1 3/4 times

Figure 3. Knee joint assembly with drum half cut away and access plate removed. Lower tibial portion not shown.

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SIMULATION OF PARAPLEGIC POSTURAL CONTROL INDUCED BY FUNCTIONAL NEUROMUSCULAR STIMULATION

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ABSTRACT

A planar computer model has been developed to investigate paraplegic posture induced by functional neuromuscular stimulation. The model consists of muscle dynamics (pulse train activation dynamics and contraction dynamics), skeletal dynamics, and output feedback. An activation distribution is implemented to minimize energy expenditure of muscles. The use of energy optimization as a performance measure was motivated by an assumption that minimization of muscle energy liberation can lessen muscle fatigue, which is a limiting factor in paraplegic posture. The employed feedback control strategy is to compute the bounded joint activation and distribute it based on energy optimization. While all the angular variables need to be measured or estimated to generate fine regulation of motion, the current control law does not require measurement of muscle or joint torque.

The simulation results showed a consistent activation sequence;i.e. strong muscles should be used earlier than weak ones. The reason is that energy liberation rate heavily depends on the relative amount of activation and, to produce a given force, strong muscles would not have to be activated as much as weak ones.

It was also shown that among major muscles in the lower extremities, soleus, vasti and hamstrings accelerate the segments from a flexed position toward the upright position. On the other hand, gastrocnemius and tibialis anterior significantly decelerate not only the shank and the thigh but the trunk as well. The reason is that reaction forces at joints cause all body segments to move, even those to which a muscle is unattached.

INTRODUCTION

Persons with paraplegia resulting from spinal cord injury need to regain functional use of their legs. Since the resulting paraplegia can be permanent, it is very important to have them regain their mobility. It has been demonstrated that functional neuromuscular stimulation (FNS) can induce rudimentary standing and walking in paraplegics. Although FNS is a potentially useful method, many problems must be solved before FNS becomes practically acceptable.

We have chosen to develop computer models since they are very helpful in designing automatic control strategies and in studying the trade-offs among different control schemes. The need for computer models is accentuated when one tries to automatically regulate balance and movement of a multiple degree-of-freedom body being acted upon by external disturbances like arm manipulation.

The objective of the present study is to build a sufficiently reasonable computer model to investigate human paraplegic postural control induced by FNS. The control criteria are (a) the overall system should be output controllable and observable, (b) external disturbances such as upper body movement need to be overcome and (c) one needs to minimize muscle fatigue.

BACKGROUND

The overall dynamics is decomposed into four parts, activation dynamics, contraction dynamics, skeletal dynamics and output feedback control. Activation dynamics describes how the activation is related to the FNS input, which is assumed to be a set of rectangular pulse trains. Contraction dynamics generates muscle tension that results in skeletal motion depending on skeletal dynamics. The measured output is fedback to produce the appropriate FNS input.

Activation dynamics

Since the FNS input can be characterized by two parameters, pulse width d and pulse frequency f if one assumes the pulse amplitude is constant, muscle force is controlled by adjusting d (recruitment modulation) and f (rate modulation). The proposed model for activation dynamics (4) is

$$a(t) = a_m(d) \exp\{ -(t - kT_s)/T_c \} \text{ for } kT_s \le t < (k+1)T_s,\ k=0,1,\ldots, \quad (1)$$

where $a_m(d)$ represents the recruitment curve (2), $T_s=1/f$ and T_c is the decaying time constant of muscle activation. We adjusted the parameters in (1) to match experimental observations on human twitches induced by pulse stimulation.

Contraction dynamics

The model for contraction dynamics is based on the musculotendon actuator model developed in (7). The model consists of three elements, a contractile element (CE), a series elastic element (SEE) and an elastic tendon (TD). The first two elements, CE and SEE, are activation-dependent, while TD is not.

In order to avoid the nonlinearity of contraction dynamics, the isometric contraction was simulated for each muscle and approximated by a first-order differential equation. Since we are interested in motion around the upright posture, it can be assumed that the isometric force and the moment arm are length-independent. Thus the model for contraction dynamics is

$$d\tau_i/dt = -c_i\tau_i + c_i\tau_{oi}a(t), \quad (2)$$

where τ_i and τ_{oi} are torque and isometric torque of the i-th muscle, respectively. The c_i 's were selected by comparing tension development during isometric contraction as given by (2) with that derived by a more complex dynamic representation in (7).

Skeletal dynamics

The skeletal model in the present study is planar, accounting for the anterior-posterior motion of the body. It is assumed that the body segments are bilaterally symmetric and muscle contraction is caused by simultaneous stimulation of muscles of both legs. The skeletal model is composed of five segments, foot, shank, thigh, trunk and head, and upper extremities, which are connected by hinge joints (Fig. 1) The foot is always assumed flat on the ground. A quasi-static analysis was adopted to model the arm motion as external disturbances so that the arm motion can be replaced by a force (F_{dv} and F_{dh}) and a torque (T_d) acting on the shoulder.

The equation of motion is linearized about the upright position since our earlier study (4) showed that linearization of the skeletal model is valid in the range of $50° \le \theta_i \le 130°$ (i=1,...,3). The linearized equation of motion in the absence of external disturbances is

$$d^2\Theta/dt^2 = A_\theta\,\Theta + B_\theta\,T\,, \quad (3)$$

where $\Theta=[\Delta\theta_1..\Delta\theta_3]^T$ and $T=[\Delta T_1..\Delta T_3]^T$ denote increments from the operating position and A_θ and B_θ are constant matrices.

Energy liberation of muscle

Energy liberation rate has been formulated as a linear function of muscle force and the amount of activation. Energy liberated by muscle consists mainly of heat and work. Heat generated by muscle can be classified into three components, the resting heat, the recovery heat and the initial heat. The resting heat is neglected in this study because it is quantitatively small compared with the initial heat. The recovery heat is also omitted since recovery takes quite a long time, sometimes even days, whereas we are concerned about posture lasting only for minutes. The initial heat in a tetanus is decomposed into isometric heat and excessive heat liberated during muscle fiber shortening.

Due to the lack of experimental data on human muscles, it is assumed that all normalized numerical data from frog muscles apply to human muscles. Since the available data were obtained at 0°*C*, correction was done to describe muscle contractions at ambient body temperature assuming that the thermal dependence of variables is uniform between 0°*C* and 37°*C*.

Isometric heat (h_i). During an isometric tetanus, the total heat can be expressed as a sum of two components, the labile maintenance heat (LMH) and the stable maintenance heat (SMH) (6). The LMH rate, which decreases in an exponential fashion with time, can be neglected since the total amount of the LMH is much smaller than that of the SMH. The SMH rate consists of a tension-dependent component and a tension-independent (but activation-dependent) component. The latter accounts for about 25% of the total SMH at 0°C (1). The isometric heat rate is, after modification due to thermal dependence of heat liberation,

$$d(h_i/P_o l_o)/dt = 1.178\,(P/P_o) + 0.020\,a(t), \qquad (4)$$

where P_o and l_o represent isometric muscle force and optimal muscle fiber length, respectively.

Shortening heat (h_s). When shortening of muscle fibers is allowed, muscle liberates excessive heat, the shortening heat (SH), over the isometric heat, and performs external work. We used Hill's 1938 expression for the SH rate, although it was later modified by him, because our simulation results showed little difference between the two. The SH rate is

$$dh_s/dt = P_o a_o a(t) v^{CE}\,, \qquad (5)$$

where $a_o \cong 0.25$ and v^{CE} is the shortening velocity of the CE.

Formulation of energy rate. Before we discuss the overall formulation, energy balance needs to be considered. The total energy is liberated in the form of muscle heat, work by the three elements (CE, SEE and TD) and stored energy in the elastic elements. It should be noted that the work done by an elastic element quantitatively cancels the energy stored in the elastic element so that the total energy is the sum of the heat and the work done by the CE (w^{CE}).

The energy liberation rate has been formulated as follows. Considering $dw^{CE}/dt = Pv^{CE}$ and Hill's force-velocity equation with the effect of the activation added (7),

$$v^{CE} = V_{max} a_o (P_o a(t) - P)/(P + P_o a_o a(t)), \qquad (6)$$

where V_{max} is the maximum shortening velocity of muscle fiber, one obtains

$$dh_s/dt + dw^{CE}/dt = (P_o a_o a(t) + P) v^{CE}. \qquad (7)$$

Thus the overall rate (dE/dt) can be expressed as

$$d(E/P_o l_o)/dt = (1.178 - a_o \frac{V_{max}}{l_o}) \frac{P}{P_o} + (\,0.020 + a_o \frac{V_{max}}{l_o})\, a(t). \qquad (8)$$

METHODS

Simplification of the control system

Although the state equations can be easily established based on the linear dynamics, simplification is still necessary due to the constraint on the activation (i.e. the input). The bound of the activation comes from the fact (a) that the activation cannot be negative, and (b) that muscles are not of infinite strength.

As a first approach, we lumped muscles involved at each joint into one joint-torque (σ) actuator which, also has first-order linear dynamics and a constraint on the upper and lower values of the lumped activation $\alpha_i(t)$ (i=1,..,3). The time constant of the first-order dynamics was determined by simulating isometric force development of each lumped muscle group based on nonlinear contraction dynamics (7). The boundary values of the lumped activation depend on the torque generating capabilities of all the muscles crossing that joint. Double joint muscles were separated into two single joint muscles.

One can now formulate a set of simplified state equations in the absence of external disturbances.

$$\begin{aligned} \dot{x}_s(t) &= A_s\, x_s(t) + B_s\, a_s(t), \\ y_s(t) &= C_s\, x_s(t), \text{ and} \qquad (9) \\ a_s(t) &= -K\, y_s(t), \end{aligned}$$

where $x_s = [\Delta\theta_1 .. \Delta\theta_3\ \Delta\theta_1 .. \Delta\theta_3\ \ \Delta\sigma_1 .. \Delta\sigma_3]^T$, $a_s = [\Delta\alpha_1 .. \Delta\alpha_3]^T$, y_s is the output vector, and K is the output feedback gain. Linear optimal control theory was employed to determine K, using the following performance criterion

$$J = \frac{1}{2}\int_0^\infty (\,x_s^T R_1 x_s + a_s^T R_2 a_s\,)\, dt. \qquad (10)$$

Properly chosen weighting matrices R_1 and R_2 together with (9) give rise to a unique K if the dependence of K on the initial state is eliminated by averaging the performance obtained for a linearly independent set of initial states (5).

Activation distribution

The next step is to distribute the computed lumped activation within each muscle group such that the chosen muscles can exert the required torques. In order to achieve this aim, we added another constraint that energy liberated by muscles during a time step δt should be minimized: thus the problem is to, at time t, find the $a_i(t)$'s (i=1,...,n_m, n_m: # of muscles) to minimize

$$J_a = \sum_{i=1}^{n_m} \int_t^{t+\delta t} \dot{E}_i\ d\eta, \qquad (11)$$

where $\dot{E}_i$ denotes the energy liberation rate of the i-th muscle (see (7)), subject to a constraint that the resulting joint torques at $t+\delta t$ should match that expected from the simplified system (9).

We used in the simulation 13 muscles in the lower extremities: soleus (SOL), gastrocnemius (GAS), tibialis anterior (TA), extensor hallucis longus (EHL), extensor digitorum longus (EDL), peroneus tertius (PT), vasti (VAS), rectus femoris (RF), iliopsoas (IL), adductor magnus (AM), gluteus maximus (Gmax), gluteus medius (Gmed), and hamstrings (HAM). The muscle specific parameters, such as isometric force, were taken from (3) and assumed constant within ±10° of deviations from the upright position.

RESULTS

Muscle activation sequence

The order of recruitment of muscles was very consistent from one simulation trial to another, when energy was optimized. When a specific torque is needed at a prescribed time as in our control scheme, (a) strong (by "strong" we mean the capability of producing high isometric torque about the involved joint) muscles have to be used earlier than weak ones: e.g. in order to dorsiflex the ankle, TA is used first and followed by EHL when TA alone is not strong enough to generate the desired torque, and (b) the activation sequence also depends on the rate of tension development (V_{ten}), which is proportional to c in (2): one needs to use fast muscles rather than slow ones.

Limb dynamics

Without loss of generality, let's define extension and flexion of segments as illustrated in Fig. 1. It is assumed that, at the initial position, θ_1 is greater than or equal to 90°, and the intersegmental angles of the knee (θ_k) and the hip (θ_h) are less than or equal to 180° (e.g. as shown in Fig. 1).

The simulation results indicate that, from a flexed position, SOL, VAS and HAM in general contribute most to acceleration toward the vertical position and GAS and TA are dominantly used as decelerators. It implies that SOL and GAS act as antagonists to the shank although they exert ankle joint torques in the same direction. It was also shown that extension and flexion of a segment is affected by muscles which are not attached to the segment itself. For instance, although SOL exerts a segmental torque to the shank only, it extends the thigh and even the trunk as well as the shank.

The contribution of the angular velocities to the acceleration vector appears to be negligibly small. The acceleration vector can be decomposed into three components, when no disturbances exist, by multiplying the inverse of the inertia matrix to both sides of the equation of motion. The resulting three acceleration terms are due to angular velocities, gravity, and muscle forces, respectively. We found that the latter two components are dominant, which validates the linearization of skeletal dynamics.

DISCUSSION

Dynamics

There are three reasons for which our analytical expression for activation dynamics is adequate for the control system design: (a) it accounts for the major FNS characteristics relating pulse parameters to the activation, (b) the model can be simplified in such a way that one can deal with the control system design without considering nonlinearities lying in the activation process, and (c) the present expression is easily modifiable for use in modelling fatigue.

In the present postural control model, the sagittal motion can account for most of the three dimensional body motion, provided that (a) bilateral symmetry is assumed among the segmental parameters and the stimulation pattern, (b) the foot is flat on the ground, and (c) the subject maintains wide stance.

Passive elasticity

Preliminarily, passive joint torques seem to enhance joint stiffness in such a way that, when a joint gets hyperextended, the passive torque becomes dominant and drives the involved segments back to the upright posture. As a result, the upright position would be recovered and stabilized with less muscular effort. Therefore, further research is needed to utilize passive joint torques for segmental motion control associated with posture and walking, since it is highly nonlinear with respect to angular position and velocity, so that overall linearization is not valid. Piecewise linearization is one way to represent the passive joint torque. However, jerky motion could be expected at the moment when the controller characteristics change discontinuously.

Control law

The current output-feedback control law requires no torque measurement, though the position and the angular velocity should be measured. The reasons are that (a) it is impossible to stabilize an inherently unstable system by position feedback alone, since openloop pole positions are not affected by position feedback, (b) additional measurement of torque does not enhance performance much and (c) our activation distribution scheme needs no measurement.

The present control scheme enables us to eliminate the key limiting factors to the control system design, bound input and muscle redundancy. One of the continuing research issues is to develop a control law that regulates the positions of the center of foot pressure and the mass center in order to prevent the body from collapsing.

Muscle activation sequence based on energy optimization

There are two reasons why strong and fast muscles need to be used earlier than weak and slow ones, respectively. Firstly, the energy rate depends heavily on the relative amount of activation so that strong ones would not have to be activated as much as weak ones. Secondly, the proposed control strategy requires a specific torque at a prescribed time so that recruiting a fast muscle would consume less energy than activating multiple slow muscles.

If muscles of equal strength are fully activated, three parameters in contraction dynamics affect the amount of energy liberation when the muscles are in isometric condition and in steady-state: (a) muscles with long tendons consume more energy since their tendons are less stiff and thus their muscle fibers shorten more, (b) muscles with long fibers generate more energy since they have more sarcomeres in series, and (c) muscles containing a high percentage of fast fibers dissipate more energy due to their fast V_{max}. One can conclude that, when a specific torque is needed regardless of the elapsed time, it is desirable to select among muscles of equal strength those having short fibers and tendon, and few fast fibers.

Limb dynamics

The simulation results led us to make three suggestions about limb dynamics. Even though a muscle produces a segmental torque in a fixed direction at all times, the resulting segmental acceleration may not be always in the same direction; e.g. the direction of torque exerted by GAS on the shank is opposite to the direction of the shank acceleration caused by GAS near the upright position. Acceleration of a segment is also affected by muscles that are not attached to the segment due to dynamic coupling. For instance, SOL either extends or flexes the thigh and the trunk depending on the angular orientation of the body, whereas SOL always extends the shank; i.e. if the intersegmental angle of the knee (θ_k) is greater than 90°, SOL extends the thigh, but it flexes the thigh when θ_k<90° since the reaction force at the knee joint created by SOL causes the thigh to either extend or flex, respectively. Directions of segmental accelerations induced by muscles depend on the angular position, the skeletal parameters, and skeletal model, and therefore the above two results about segmental accelerations may not be true, once the dynamics of the body changes, as in the swing phase of walking.

CONCLUSIONS

(a) We believe that our model is sufficiently reasonable to investigate some of the control system design issues.

(b) To minimize energy expenditure by muscles, one should activate strong and fast muscles earlier than weak and slow ones, respectively, when a specific torque is needed at a prescribed instant of time.

(c) If muscles are equally strong and a specific torque is needed regardless of time, three muscle specific parameters should be considered to determine the activation sequence. They are resting tendon length, optimal muscle fiber length, and fiber type distribution.

(d) The direction of a muscle torque on a segment may be opposite to that of the segmental acceleration induced by the muscle.

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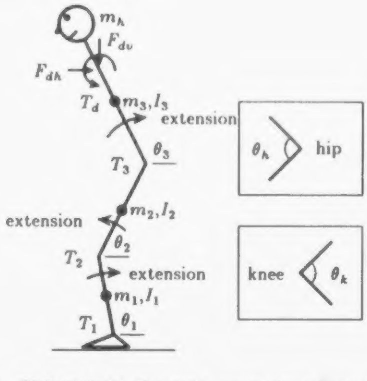

Figure 1. Skeletal Model : The angles are relative to the horizontal plane. T_i (i=1,..,3) is the joint torque at joint i caused by the forces of all muscles crossing joint i. Note extension of segments is defined by the arrows (see RESULTS).

TOWARDS THE MANUFACTURE OF AN IDEAL ARTIFICIAL NERVE GROWTH MEDIUM

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ABSTRACT

An artificial nerve graft (ANG) can replace an autograft in the management of a large nerve gap. Currently, the major obstacle to the manufacture of an ideal ANG is the development of an ideal axonal growth medium.The proximal nerve crush method is designed to allow the nerve to manufacture its own endoneurial environment for biochemical analysis. Thus, the biochemical composition of an ideal axonal growth medium can be ellucidated. The principal goal of this method is to provide an immediate distal stump environment for the growth cones of regenerating axons while an ideal growth medium of the ANG can be manufactured by the nerve itself. This can be accomplished by crushing the proximal stump a distance "G" from its transected end. Thus, the growth cones of regenerating axons are located at the crush site. In this proximal crush method, the regenerating ends of the axons are initially exposed to a distal stump environment provided by the segment of nerve distal to the crush while the environment within the ANG, which is located at the end of this segment, is being "automanufactured" by the transected ends of the nerve. By the time that the growth cones reach the ANG, the medium of the ANG is fully "matured" and provides them a favorable environment for regeneration.

INTRODUCTION AND BACKGROUND

In cases of peripheral nerve injuries, every effort is made to obtain a direct end-to-end anastomosis. However, there are instances where a gap that resulted from resection of damaged nerve is too wide for such an anatomosis despite extensive mobilization and rerouting. A nerve graft is then necessary to bridge the graft. Because of the limited availability of autografts, an ANG is very desirable.

Previous work on the development of an ANG has been done in this laboratory. The ANG was initially composed of a polygycolic acid (PGA) tube filled with a hypoallergenic collagen medium. The result of axonal regeneration in this ANG model was inferior to that of the autograft (30). The major obstacle to the goal of manufacturing an ideal ANG is the development of an ideal endoneurial environment. Such an environment is most likely composed of both cellular components and extracellular components already present in the nerve itself. Therefore, the restoration of the right amount of all of these components in a timely fashion is crucial for the functional recovery of the injured nerve.

This study is designed to allow the nerve to manufacture its own endoneurial environment which must be ideal in theory. The method is based on experiments by Politis and Lundborg which showed that the presence of the distal stump is a necessary prerequisite for the successful regeneration of the nerve and that its influence is effective only a short distance (19,26). More recently, a 37-kilodalton (kD) protein was found in the distal segment of crushed rat sciatic nerve (34). The manufacture of the 37-kD protein was found well after the injury suggesting that it has a role in *de novo* nerve growth and in nerve repair (25). In a recent conference, this group reported that this 37-kD protein is probably the Apo-E lipoprotein which is involved with the transport of lipid during nerve regeneration. In the proximal nerve crush method, a crush is made a distant "G" proximal to the transected end of the nerve, thus, it allows the growth cones of regenerating axons to be exposed to a favorable environment of the distal stump immediately after repair. As these cones grow within the nerve segment "G", the composition growth medium of the ANG is altered by the proximal and distal stumps. When these cones reach the ANG, the ANG is matured and provides a ideal environment for axonal regeneration.

METHODS AND MATERIALS

There will be two parts to this study but only the first part is presented here. The first part is designed to compare axonal regeneration in the new method (Figure 1) versus the current method of nerve repair (Figure 2) with an artificial nerve graft. The second part is designed to compare axonal regeneration in the new method of nerve repair with an artificial nerve graft with the standard method of nerve repair with an autograft.

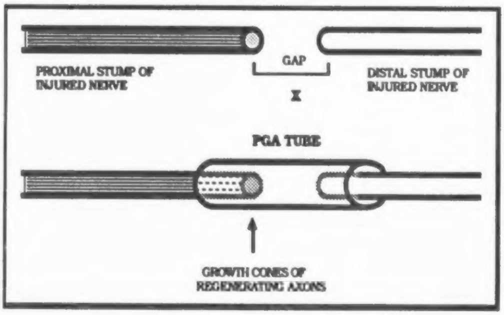
PROXIMAL STUMP OF INJURED NERVE
GAP
X
DISTAL STUMP OF INJURED NERVE
PGA TUBE
GROWTH CONES OF REGENERATING AXONS

Figure 1 - Current Method of Nerve Repair with an Artificial Nerve Graft.

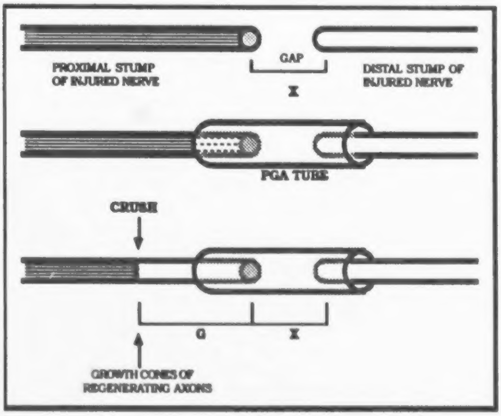
PROXIMAL STUMP OF INJURED NERVE
GAP
X
DISTAL STUMP OF INJURED NERVE
PGA TUBE
CRUSH
G
X
GROWTH CONES OF REGENERATING AXONS

Figure 2 - Proximal Nerve Crush Method of Nerve Repair with an Artificial Nerve Graft.

In part one of the study, the animals are anesthetized with intraperitoneal sodium pentobarbital (3-5 mg/100 gm.of body weight). All surgical dissections and repairs are done under magnification of 10 to 25X. In each animal, both peroneal nerves are exposed and transected sharply, using microscissors, one centimeter distal to the trifurcation of the sciatic nerve into the peroneal, tibial and sural nerve branches. A 5.0 mm long segment of nerve is removed from the distal transected portion of each nerve. One randomized side in each animal is repaired using an artificial nerve graft (ANG) using the current method. The artificial nerve graft is composed of a polyglycolic acid (PGA) tube (Available from Davis and Geck, Pearl River, NY), 1.0 mm in diameter and 10.0 mm long filled with serous fluid present in the surgical wound. The PGA tubes are split longitudinally and soaked in saline. Both ends of the transected nerve are pulled 2.5 mm into the tube and secured in place with a blood clot. The other side in each animal are repaired using an artificial nerve graft using the proximal nerve crush method. In the proximal nerve crush method, the proximal stump is crushed 5.0 mm from the proximal transected end first, then both ends of the transected nerve are pulled 2.5 mm into the tube, thus leaving a gap of 5.0 mm between the transected ends.

Nerve regeneration are evaluated at 0.5, 1, 3 months (short-term study) and at 6 months (long-term study). In the short-term study, total of thirty animals (ten in each group) will be used for evaluation by qualitative histology and transmission electron microscopy and a total of twenty animals will be used in the long-term study for evaluation by qualitative and quantitative histology, transmission electron microscopy, and electrophysiology.

RESULTS

In the first part of the study, axonal regeneration in twelve animals have been evaluated, so far, by qualitative histology at 0.5, 1, 3 months after repair. There was a technical failure in two animals where the nerve ends were found outside the tube.

At 0.5 month, three animals have been evaluated. Within the ANG, there is evidence of some small axons with thin layer of myelin in the current method, whereas, in the proximal nerve crush method, there is only fibroblasts in an amorphous background.

At 1 month, three animals have been evaluated. Again, no significant changes from earlier observations are noted. There is evidence of breakdown of the PGA tube.

At 3 months, four animals have been evaluated. In the current method, the axons tend to be in the center of the ANG with minimal fatty changes. In the proximal nerve crush method, there is notably more fatty infiltrate with multiple bundles of myelinated axons permeating among the fat cells. Cross-sections of the distal nerve stump reveal remarkably good axonal regeneration in both methods. Hoewever, the number and size of the axons in the proximal nerve crush method appear to be larger those in the current method but quantitative evaluation methods must be done for objective comparison.

Further results will be presented at the time of the meeting.

DISCUSSION

Early artificial nerve grafts consisted of a tube filled with blood or some plasma products to fill in the gap (10). In other cases, only threads were used to direct the growth of axons from the proximal to the distal end of the resected nerve with no surrounding tube (35). These attempts were generally unsuccessful. In the 40's, Weiss used arteries and freeze-dried arteries filled with blood as guiding tubes for regeneration of severed nerves (36, 37). His experiments concluded that tubes filled with blood (with or without threads as guides) would successfully allow axonal growth and thus act as an artificial nerve graft. Recently, experiments using autogenous veins as passive conduits for nerve regeneration found them acceptable but far from being an ideal nerve graft (5, 6). Other work using pseudosynovial or mesothelial tube have reported moderate success (15-18, 20), while others experimenting with various synthetic resorbable non-resorbable materials also had some success (7, 9, 19, 24).

The introduction of polyglycolic acid (PGA) as a biodegradable material for various uses in tissue repair has provided an ideal synthetic material for the manufacture of the guide tube of the artificial nerve graft. PGA is a polymer which is completely hydrolysed with minimal inflammation (1, 2, 11, 23, 27, 29). Several recent studies have evaluated PGA tubes filled with blood as an artificial nerve graft (9, 33). The results were generally poor despite the use of the PGA tube which provides an ideal passive conduit for axonal regeneration. Therefore, it is obvious that a more ideal growth medium for axonal regeneration is critically important for better functional recovery of resected nerves.

The discovery of the nerve growth factor (14) and its purification (8) have changed the long held Wallerian theory of the nerve cell body as the trophic center that supports the distal nerve's existence, function, and regeneration. These factors, also known as neuronotrophic factors, are most often macromolecular proteins synthesized by various cell lines within the nerve. Therefore, several natural components of the peripheral nerve will probably play a crucial role in axonal regeneration, and their purification and incorporation in the growth medium will be a crucial step towards the manufacture of an ideal growth medium.

The interaction of neuronal processes with the surface or substratum on which they grow has been a subject of increasing interest. It is now well established that in gap lesions, the lack of structure to guide axonal advancement will lead to randomized growth causing neuromas. This phenomenon was observed in the study comparing transected nerves versus crushed nerves (12). The basal lamina is preserved in the crushed nerve and thus acts as a guide tube or mechanical scaffolding through which the axons could grow (12, 13). Furthermore, laminin, a structural component of the basal lamina, was found to have a neurotrophic effect on axonal regeneration (21, 22, 28, 32). Thus, the basal lamina can serve both as a guiding structure and a trophic substrate for axonal regeneration. Several studies have evaluated the trophic effect of other macromolecules found in the endoneurial environment such as collagen (30), connective tissue matrix or extracellular matrix (4), and fibronectin (28) on regenerating axons.

Lundborg's work on regenerating nerve in pseudosynovial tube reported that the serum harvested from within the mesothelial chamber was found to have a strong neurotrophic influence on growing neurites in tissue culture (16, 18). In addition, experiments by Politis and Lundborg have shown that the presence of the distal stump is a necessary prerequisite for the successful regeneration of the nerve and that its influence is effective only a short distance (19, 26). More recently, Shooter's group has described the increased synthesis and secretion of a 37-kilodalton (kD) protein in the distal segment of crushed rat sciatic nerve (34). This group also has shown that the manufacture of the 37-kD protein occurs well after the time of injury suggesting that it has a role in *de novo* nerve growth and in nerve repair (25). In a recent conference, this group reported that this 37-kD protein is probably the Apo-E lipoprotein which is involved with the transport of lipid.They postulated that the 37-kD protein is synthesized by macrophages or Schwann cells for the transport of metabolized lipids from the breakdown of the transected distal axons to the proximal end of the transected nerve for the synthesis of new membrane of the growth cone.

CONCLUSIONS

Although only experimental result in short-term animals are currently available. The proximal nerve crush method seems to make a definite positive difference in the pattern of axonal regeneration from the current method of nerve repair with an ANG. Results from the evaluation of long-term animals will provide quantitative information. If the proximal nerve crush method should provide a definite advantage over the current method and, even more importantly, over the sutured autograft, then biochemical analysis of the composition of the ANG will provide the formula for the manufacture of the ideal axonal growth medium.

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ISCHIAL BLOOD FLOW OF SEATED INDIVIDUALS DURING ELECTRICAL MUSCLE STIMULATION

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ABSTRACT

Ischial blood flow has been measured in seated able-bodied and spinal cord injured (SCI) individuals while electrically stimulating the gluteus muscles. Muscle blood flow was measured via radioactive tracer (^{133}Xenon) clearance. Retention of Xenon in adipose tissue prevented accurate measurement of blood flow in cutaneous and subcutaneous tissue. Blood flow in both subject groups was increased during stimulation as compared to rest, however, the statistical significance for able-bodied subjects ($p < .05$) was greater than that for SCI subjects ($.12 < p < .15$). The measurable increase in muscle blood flow produced by electrical muscle stimulation (EMS) in seated individuals supports the hypothesis that EMS can help prevent pressure sores.

INTRODUCTION

Ulceration of the skin commonly occurs when external forces are applied over a period of time without relief. These ulcers are typically referred to as pressure sores, decubitus ulcers, ischemic sores, etc. These sores are a severe and costly problem for many disabled individuals and are most significant for those who are wheelchair dependent and have sensory loss. A research study is in progress to determine whether electrical muscle stimulation (EMS) can be used to prevent the formation of pressure sores. Our previous work in this area (1,2) has shown that even at low intensity (easily tolerated by sensate subjects), EMS can produce substantial interface pressure variation, tissue undulation, and shape reconfiguration of the buttocks under load (while seated).

Pressure sore etiology is a complicated event involving many parameters, but most investigators agree that a primary event leading to pressure sore formation is blood flow occlusion. Occlusion of lymph vessels and disturbance of interstitial fluid flow are also important factors (3). The current study was designed to investigate the effects of EMS on muscle blood flow. Blood flow studies provide an opportunity to quantify the potential efficacy of various EMS paradigms and should be valuable in designing stimulation parameters for future clinical trials.

METHODS

Blood flow studies were performed on eight able bodied (AB) subjects and six spinal cord injured (SCI) subjects. The test protocol for AB subjects began with a 30 minute rest period (A) before stimulation. A 12 minute stimulation period (B) followed rest period A and consisted of 3 separate 2 minute periods of EMS each followed by a 2 minute rest period. Thirty minutes of rest (period C) followed stimulation period B.

All SCI subjects had acute onset of sensory and motor paralysis from the waist down (i.e. at or above the T10 level). One individual was sensory incomplete; the rest were motor and sensory complete. None of the subjects had a history of pressure sores under the ischial tuberosities. The same test protocol was carried out with the SCI group except that the rest periods before and after stimulation (periods A and C) were shortened to 20 minutes to minimize tissue trauma. All other parameters and procedures were identical to the protocal used with the AB subjects.

Radioactive ^{133}Xenon was injected at the site of the ischial tuberosity. Each subject received a subcutaneous injection on one side and an intramuscular injection in the other. During stimulation a wide field-of-view gamma camera, with a selectively designed collimator, was positioned under the subject close to the injection site. Sequential scintigraphic images of the injection site were recorded every 5 seconds throughout the trial during both rest and EMS periods.

Following imaging, a time-activity plot of the ^{133}Xe washout was obtained for each injection site. The slope, K, of the semilogarithmic plot was used to calculate blood flow according to the following formula:

$$\text{regional blood flow (ml/100g tissue/minute)} = 100 \times \text{lambda} \times K$$

where lambda is the tissue/blood partition coefficient. Lambda for Xenon is 9.9 ml/g in fat and 0.7 ml/g in muscle and skin. Average blood flows were determined for the entire initial rest period A, ten minute subsets of period A, the entire 12 minute stimulation period B, and the entire final rest period C.

A special chair was designed to simulate standard wheelchair sitting and permit access for the gamma camera. The chair had a backrest to seat angle of 90 degrees, a minimum two inch clearance from the popliteal fossa to the forward edge of the wheelchair, and adjustable footrests to keep the thighs parallel to the seat and floor. A two inch medium density foam cushion was used.

Pressure measurements were made simultaneously with ^{133}Xe clearance data for comparison of blood flow with the magnitude of muscle contraction. A Texas Interface Pressure Evaluator (TIPE) pad [a] and a specialized computer interface developed in our laboratory (4) were used to monitor pressure distribution changes. The TIPE pad is an inflatable 18" square cushion with a 12 x 12 matrix of activation switches. Each switch can be opened or closed independently. A closed switch indicates that the external pressure exceeds the pad inflation pressure. The TIPE pad was placed between the foam seat cushion and the seated subject. The number of switch transitions (from open to closed or closed to open) during stimulation was used to indicate the strength of muscle contraction. Custom software for the computerized TIPE pad interface was used to collect and store real-time data.

Stimulation was provided through surface electrodes using a dual channel neuromuscular stimulator^{b}. The stimulating cathodes were positioned bilaterally on the gluteus maximus at a point producing maximum contraction for a given intensity as determined through monopolar stimulation and visual inspection. (This point was always off of the seating contact surface so that frictional irritation was not a problem.) The anode was placed on the sacrum. Stimulation frequency was set at 50 hz. and applied with a duty cycle of 2 seconds on / 4 seconds off. The current amplitude was set to produce 5-6 TIPE pad switch transitions with stimulation (2).

RESULTS

Rest and stimulation periods were divided into various subsets for statistical analysis. The last 10 minute subset of period A and the entire 30 minute rest period C were compared with:
1) the stimulator "on" time during period B;
2) the stimulator "off" time during period B; and
3) the entire stimulation period B.
(The rationale for looking at 10 minute subsets of period A was to acccount for any time varying behavior of blood flow from initial seating). A paired t-test was used for statistical analysis. Results are shown in the Table below.

F = blood flow in ml/100g/min
p = statistical significance from paired t-tests

Able-Bodied Subjects

rest A-last 10 min F =.0082	p=.04	p=.05	p=.46
rest C-all F=.0069	p=.01	p=.21	p=.04
	Stim On F=.0131	Stim Off F=.0052	Stim Both F=.0091

SCI Subjects

rest A-last 10 min F=.0134	p=.15	p=.36	p=.17
rest C-all F=.0134	p=.12	p=.16	p=.12
	Stim On F=.0383	Stim Off F=.0174	Stim Both F=.0279

TABLE. Blood flow values and paired t-test significance levels for AB and SCI subjects.

Blood flow data from the subcutaneous injection proved to be unobtainable due to the high partition coefficient for Xenon in adipose tissue as compared to muscle and skin (9.9 vs 0.7 ml/g). In fact, subcutaneous wash out was slow enough that in many scintigraphic images the number of counts apparently increased within the imaged area (i.e. there was "wash in"). This error was most likely due to movement artifacts and other measurement inaccuracies.

DISCUSSION

Blood flow in the muscle during EMS was increased significantly ($p < .05$) when compared to blood flow preceding or following EMS intervention for AB subjects. Blood flow in SCI subjects was also increased during EMS but not at a statistically significant level ($.12 < p < .15$). (Blood flow for SCI subjects during stimulation was always greater than that during any of the rest periods). The "best case" of blood flow vs. time for an SCI subject is shown in Figure 1. Reduced statistical significance for SCI subjects is due, in part, to a relatively large variance between subjects in blood flow measurements. Increasing the number of SCI subjects could be expected to produce statistically significant results. Another consideration with the SCI subjects is that none of them had any pre-conditioning of their gluteus maximus so that fatigue and weaker contractions (as compared to AB subjects) may also have been a factor. Figure 2 shows a clear example of fatigue in one SCI subject where the number of switch transitions decreased over time during stimulation period B.

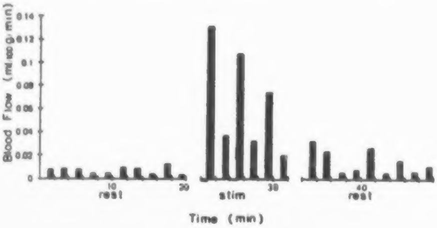

FIGURE 1. Blood flow plotted vs. time for a spinal cord injured subject.

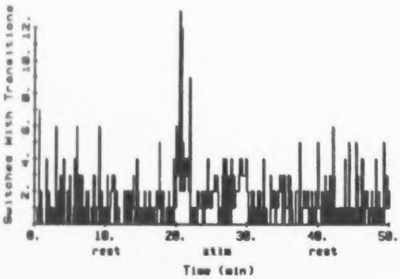

FIGURE 2. Plot of TIPE pad switch transitions vs. time for an SCI subject (a measure of muscle activity).

Blood flow during the two minute rest periods in between stimulation in period B was significantly decreased for AB subjects as compared to blood flow in the last 10 minutes of rest period A. These "rest" blood flows in period B were not reduced in comparison to rest period C. No such decrease was observed for SCI subjects during the cycle off times. One interesting hypothesis for this is that the buttock tissue of able bodied subjects exhibits viscoelastic behavior with a relatively long time constant (5). That is, the buttock tissue gradually distorts to occlude blood flow and doesn't "bottom out" (reach peak occlusion) for a relatively long period of time (i.e. 30 minutes). Another possibility is that stimulation (or AB subject anticipation of such) results in a repositioning of the buttocks relative to the gamma camera whereby an apparent decrease in blood flow is measured.

Measurement of skin and subcutaneous blood flow is an important part of evaluating the potential efficacy of EMS for pressure sore prevention. Xenon does not accurately measure subcutaneous blood flow due to its high affinity for fat. ^{99m}Technetium has been successfully used to measure skin blood flow (6). Studies are planned in the near future to measure skin blood flow during EMS using an adaptation of this technique.

EMS clearly increases muscle blood flow in the buttocks while sitting. This result supports the hypothesis that EMS may be useful in preventing pressure sores. Further work needs to include blood flow measurements in skin during EMS and evaluation of different stimulation parameters for optimal effect. However, these results do not guarantee the success of EMS in preventing pressure sores since there are also negative effects which must be considered (increased oxygen consumption, metabolite production, sweating, etc.). Clinical trials to evaluate the integrated effect of all factors are planned once optimal stimulation paradigms have been determined.

ACKNOWLEDGEMENT

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SUPPLIERS

a. RESPOND II Stimulator, Medtronic Inc.,
7000 Central Ave. NE, Minneapolis, MN 55432.

b. TIPE pressure pad, TK Applied Technologies,
11915 Meadowtrail Lane, Stafford, Texas 77477

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RESULTS OF FES APPLICATION TO 71 SCI PATIENTS

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ABSTRACT - The results and case reports are summarized regarding FES application to 71 SCI patients. FES was applied utilizing surface electrodes. For standing m.quadriceps stimulation only was employed, while for the FES enabled gait the m.quadriceps for knee locking and the flexion reflex triggered swing phase mode of gait were utilized. The patients were admitted to the FES program during the time period since 1978 to 1986. FES was applied for gait training and assist to 26 incomplete SCI patients including 9 tetraparetic and 17 paraparetic cases. FES was applied also to 45 complete SCI patients with the aim of standng and reciprocal biped walking. The results obtained in these 71 SCI patients are reviewed.

INTRODUCTION

This review of FES utilization for standing and gait assist in 71 SCI patients is covering the patient population admitted to the University Rehabilitation Center in Ljubljana in the period 1978-1986. Annually in average 50-60 hospitalized SCI patients were treated.During the period of 1976-1986, in the nine years, approximately 500 patients were admitted to the spinal unit. At the beginning the patients were included only into the FES research program for muscle restrengthening, standing and gait in parallel bars. Before 1980 there was no regular SCI clinical program for FES utilization and no commercial FES stimulators available for SCI patients in Ljubljana. Most of the patients received at that time a standing frame and a two-channel exercising stimulator also permitting standing. In 1980 the gait training was transferred from parallel bars to a frame or "bars on wheels" with the aim of allowing longer gait runs. In this way the patients were able to exercise and walk at different locations. In 1980 smaller version of exercising and standing stimulator was introduced together with the four-channel stimulator intended for walking and designed for patient's home use. In all the applications of FES described watter soaked surface electrodes were predominantly used. Several patients were for test and because of other reasons using different self-adhesive electrodes while one patient was using an experimental unilateral implant for flexion reflex triggering. The described population of 71 SCI patients does not represent a realistic sample of corresponding region in order to estimate to how many of SCI patients FES may be applied. We believe that sample is too small and also many patients admitted in last several years were coming from outside of our region. Also to note is that many of them were coming because they would like to benefit from FES treatment in addition to their standard treatment obtained elsewhere. In general, our opinion is that the numbers and statistical data presented here are close to some realistic but at present unknown numbers. Nevertheless, with the development of FES methodology through all of these years the treatment and hardware were improving constantly and more and more patients is using FES after their discharge, while for the first three years this was not the case. These first patients performed well at the time of discharge but did not continue in using FES at home due to clumsy equipment or because no equipment was available at that time. We believe that also some of the patients in the category of "parallel bars walkers" would have progressed to walker assisted or crutch assisted walking if training was regularly continued and the equipment available at the time of discharge. It is also hard to determine for the early treated patients and those who left the hospital to live in places far from Ljubljana, how would they in a long run use RES if upgraded training as well as improved equipment were available. In many patients functional status obtained after the initial FES program was higher if compared to the FES use at their homes. For this observation there are at least two reasons: first, the patients did not receive at discharge the necessary stimulators and were unable to utilize FES adequately, secondly, their hospital time was too short for obtaining a solid training. Also in some cases the home use of FES was set back because of hardware failure and secondary, because of FES unrelated problems and lack of time or willingness to use FES daily. In spite of these problems which are typical for developing treatment modalities, such as FES is, the number of patients who functionally and daily use FES for standing and gait, is reasonable good.

METHODS AND MATERIAL

The patients were selected and admitted to the FES program according to the published treatment and selection criteria /1,2,3,4,5/. To note is also that the FES program is an adjunct treatment to the standard SCI patients rehabilitation program. First, FES restrengthening of mainly m.quadriceps is performed and after achieving a level of about 30-40 Nm of torque, FES enabled standing training is started. Once sufficient standing time and safety is obtained, the patients proceed to gait training in the walking frame. For standing bilateral m.quadriceps stimulation is utilized. For gait additional two-channels for flexion reflex triggering are foreseen. The flexion reflex withdrawal movement is substituting the swing phase movement of regular gait /1,2,5/. According to the adequacy of patient's performance in gait training he is tought to use walker for safety and stability assist, or even to utilize crutches. At the time of discharge the patients may select for home use the following equipment: standing frame, wheelchair attached folding bars for standing assist, different walkers and elbow crutches adopted for stimulator triggering. There are several types of stimulators available: 1-channel peroneal devices utilized in incomplete patients for unilateral flexion reflex triggering, 2-channel exercising and standing stimulator, and 2-channel alternating stimulator for unilateral stimulation of m. quadriceps or flexion reflex. Two of such devices are needed in complete SCI while the majority of incomplete SCI patients can use one device for gait assist in stance and swing phase unilaterally for the more severely involved leg. For gait training 4-channel stimulators and special 6- or even 8-channel devices are available for patients included in the research investigations of FES. For routinely treated patients only 1, 2 or 4-channel devices are available. Here, we will concentrate on the results obtained in complete SCI patients while the results of incomplete patients will be summarized only for obtaining a complete review. For details regarding treatment and results we refer to /2,3,4/.

RESULTS

Table I is displaying the data on population of 41 SCI patients suffering from complete lesion. The 26 incomplete patients treated are not presented. Also dropped are four complete patients who left the program because of reasons not associated to FES. Totally, 500 patients were approximately admitted in the 9 years period and 14,2% of all patients admitted were FES treated. Out of 71 SCI patients 26 or 37% or in total 5,2% were included into the incomplete FES program, while 45 patients or 63% (totally 9%) were admitted to the complete lesion FES program. Here are reviewed the results obtained at the discharge. Four patients out of 45 complete lesion SCI patients left the program, 16 patients (36% or in total 3,2%) accomplished functional assisted FES standing, 7 patients (15% or in total 1,4%) were trained in parallel bars walking. Parallel bars walking was merely a training and demonstration modality in the early development of FES application to SCI patients and this mode of training is today not practiced any more. These patients left the hospital in principle without any FES devices, but would be according to the present criteria and knowledge trained for at least standing or walker utilization for FES enabled gait. Seven patients (15% or in total 1,4%) are functionally walking using different walkers, 7 patients (15% or totally 1,4%) achieved FES assisted crutch walking and 3 (6%) were admitted to the stairs walking program and accomplished ascending stairs by means of FES, one hand rail and one hand crutch support, while for descending they utilize hopping jumps (bilateral m.quadriceps stimulation). In fig.1a and b is displayed the wheelchair attached folding frame standing and a patient equipped for walking using crutches and the 4-channel stimulator.

TABLE I

OT - other
TR - traffic accident
FA - FALL
SH - shot
DV - DIVING

2 CH - 2channel FES
4 CH - 4channel fES
CR - crutches
WA - walker
WF - walking frame
SF - standing frame
PB - parallel bars
SW - standing wheel-chair frame
EX - exercising
B - additional braces
* - multiple lesions highest involved level given

No.	Sex	Level Injury Type	Injury Date	Age	Start of FES	FES Function Trained	FES Home Use
1	M	T5,6 TR	X/77	30	XII/77	4CH,PB	0
2	M	T6, TR	XII/79	27	I /85	2CH,SF	SF
3	M	T2,3,4,TR	X/81	26	II/84	4CH,WA	4CH,WA
4	M	T10,TR	VIII/85	17	X/85	4CH,CR	4CH,CR
5	M	T4,5,TR	I/85	33	X/83	2CH,SF	2CH,EX
6	M	C7,TR	VI/83	21	III/86	2CH,SF	2CH,SF
7	M	T11,12,TR	V/83	20	VIII/85	4CH,B,CR	4CH,F,CR
8	M	T5,6,TR	VIII/79	22	I/86	4CH,WA	4CH,WA
9	M	T10,11,TR	IX/80	25	III/81	2CH,SF	0
10	M	T8,TR	XII/76	16	V/83	2CH,SF	2CH,SW
11	M	T4,5,TR	X/84	25	VI/85	4CH,PB	4CH,PB
12	M	T9,10,OT	V/64	25	VI/80	2CH,EX	2CH,EX
13	M	T12,FA	V/83	19	VIII/85	2CH,EX	0
14	M	T12,FA	XII/84	14	V/85	4CH,B,CR	4CH,CR
15	M	T5,SH	IX/79	46	III/83	2CH,SF	2CH
16	M	T7,TR	VIII/80	14	VIII/85	2CH,SF	2CH,SW
17	M	T6,TR	III/79	20	IX/80	4CH,CR	4CH,CR
18	M	T6,FA	VII/85	26	XI/85	4CH,WA	4CH,WA
19	M	T10,TR	VII/78	24	II/79	4CH,PB	0
20	M	T9,TR	XI/83	20	V/84	2CH,SF	0
21	M	T6,TR	IV/83	26	II/84	2CH,SW	2CH,SW
22	M	T7,8,TR	XII/83	25	IV/84	2CH,SW	2CH,SW
23	M	T8,TR	IV/83	15	III/85	2CH,SF	2CH,SF
24	M	T10,12,TR	1/85	22	II/86	4CH,WA	4CH,WA
25	M	T11,TR	V/72	20	IX/82	2CH,SF	0
26	F	T9,FA	V/81	18	X/81	4CH,PB	lost
27	M	T5,6,TR	V/81	18	X/81	4CH,PB	2CH
28	F	C7,OT	II/82	11	IX/83	4CH,CR	4CH,CR
29	M	T4,5,TR	IV/84	22	X/85	4CH,WA	4CH,WA
30	M	OT	VI/75	33	VI/86	2CH,SF	2CH,EX
31	F	C7,T1,TR	VIII/83	21	III/84	2CH,EX	0
32	M	T4,5,TR	VII/78	17	VI/85	4CH,PB	4CH,PB
33	M	T8,FA	X/83	15	VI/85	4CH,WA	4CH,WA
34	M	T3,TR	VIII/80	16	VIII/80	2CH,SF	0
35	F	T5,OT	III/83	23	IX/84	4CH,CR	4CH,CR
36	M	T3,4,TR	VI/82	30	IV/85	2CH,SW	2CH,SW
37	M	T7,SH	VII/81	40	V/82	4CH,PB	0
38	M	T7,8,TR	V/78	31	X/84	4CH,CR	4CH,CR
39	M	C6,7,TR	VI/73	22	I/81	2CH,SF	0
40	M	C7,DV	VII/82	24	IV/84	6CH,WF	6CH,WF
41	F	T5,6,TR	V/82	26	XI/86	4CH,WA	4CH,WA

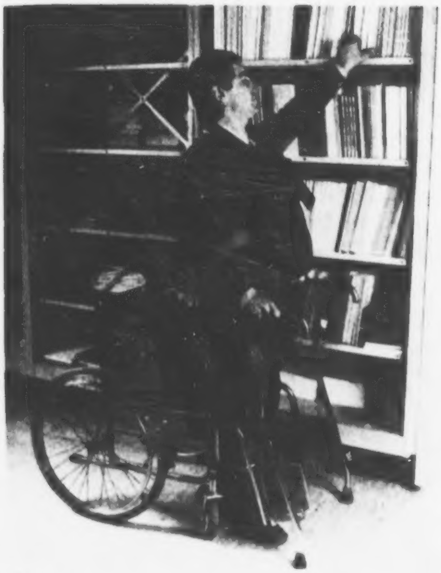

Fig. 1 a

26 incomplete SCI patients in total were admitted to the FES program. For the standing and gait training program the patients were selected if being able to stand on one leg or if they accomplished standing by additional FES of the m.quadriceps of the more severely involved leg. Only during the last several years these patients were admitted to the FES program. For these patients mainly, we introduced a two-channel stimulator for combined unilateral m.quadriceps and flexion reflex stimulation. The main problem in incomplete SCI patients is the inability to perform a step due to lack of flexion. Therefore they are able to stand but not walk and remain wheel-chair users. Equipped and trained how to use FES for the triggering of flexion reflex providing synergistic flexion and enabling the swing for a step they start to walk.Out of the 26 patients 20 or 77% use unilateral FES for flexion reflex triggering and allowing them to make a step with the more involved leg, while the less involved side is functional in stance and swing. Four patients use bilateral flexion reflex for enabling swing for gait and two patients utilize unilateral stimulation of m.quadriceps and flexion reflex. We expect that with the improvements developed in the last years and better designed stimulators more patients will be admitted to the incomplete FES program.

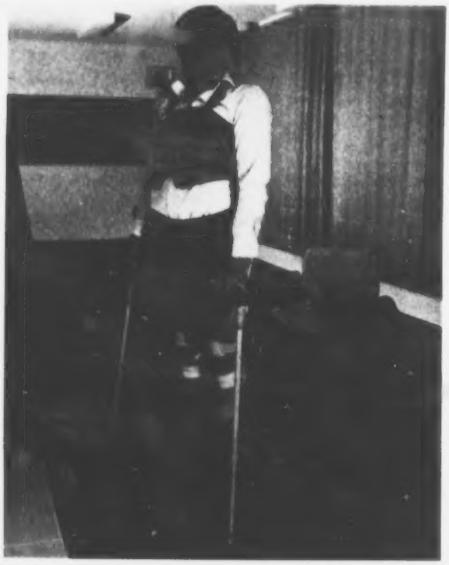

Fig. 1 b

DISCUSSION

Note that for statistical evaluation of FES treatment possibilities the numbers given here are not adequate and should be considered only as very rough approximations. They are only valid to a certain extent for the patients' population treated in our region. We believe that the number of SCI patients being candidates for FES may be noticeably higher from the here given numbers because the selection and training modalities as well as hardware are improving substantially with the years and therefore better selection and function may be provided for the patients. We would like also to draw attention to the fact that the functional status because of FES, while the patients are in the hospital, is higher but does later decline owing to the problems associated with hardware failure and sometimes unadequately completed patient training and also different FES unrelated complications.

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660

EFFICIENCY OF VOLITIONAL VERSUS ELECTRICALLY EVOKED KNEE EXTENSION EXERCISE

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ABSTRACT

The purpose of this study was to determine the efficiency of ES and voluntary (VOL) knee extension exercise. Twenty-three healthy subjects (29.5 ±5.3 yrs) performed VOL fatigue tests at 180, 120, 90 and 60°/sec. Isometric knee extension peak moment was noted and matched VOL and ES exercise was performed at 15, 25 and 33% peak isokinetic moment. An isokinetic dynamometer was interfaced with a DEO-MINC 11/23 and a computer controlled stimulator maintained the desired force output. Open circuit spirometry was employed for continuous sampling of expired gases. Repeated measures ANOVA identified differences in efficiency due to velocity, intensity and mode of exercise. The efficiency of ES exercise was 35 to 114% less than that of matched VOL effort at 60 and 90°/sec ($p<.05$). Efficiency was greater at the slower velocity ($p<.0001$) in both exercise modes. Limitation of force output and reduction of efficiency demonstrate that ES is not the equivalent of voluntary control.

INTRODUCTION

Electrical stimulation has been shown to be an effective clinical tool to activate skeletal muscle in patients who have muscular weakness secondary to limb disuse or neurological impairment. Both surface and implanted electrodes have been used to stimulate the anterior leg muscles and prevent toe drag in stroke victims. The success of this treatment is evidenced by a 13-year follow-up report on patients who still use a stimulator daily in place of an orthosis (1).

The ability of wheelchair bound victims of spinal injury to stand and walk with the aid of surface electrical stimulation has dramatically elevated interest in this mode of treatment. Multichannel implantable stimulation devices, in development, will be available for surgical implantation in human patients in the near future (2).

The relative energy demand of electrical stimulation as a substitute for voluntary activation of skeletal muscle has not been investigated. The amount of work accomplished for a given energy expenditure, or efficiency, is of particular importance when the job to be done requires repetitive use of a large muscle mass, as in walking.

BACKGROUND

The inherent flexibility of the neuromuscular system in activating skeletal muscle offers many advantages over electrically stimulated muscle contraction. The pattern of normal motor unit recruitment varies with the quality of muscle response desired. Small, slower motor units are called upon first in sub-maximal exercise. Firing rates vary from 5 to 20 Hz. Larger, faster motor units, firing up to 50 Hz, are recruited as more forceful or more rapid contraction is required (3). The active motor units, with fibers distributed widely throughout the muscle (4), fire asynchronously and have the option of a reduction in firing rate as additional motor units are called upon in the case of fatigue (5).

Electrical stimulation recruits motor units, or muscle fibers, in a different order. The lower threshold of large axons to stimulation, results in preferential recruitment of these fibers (6). The geographical distribution of the contracting muscle fibers within the muscle appears to be markedly different in electrical stimulation and synchronous firing of muscle fibers, required to produce smooth joint motion, is contrary to normal motor unit activation (7).

Electrically stimulated muscle is potentially limited by the deviations from normal muscle control. Preferential activation of fast fibers would result in increased energy requirements for a given work load due to the relative glycolytic metabolic profile of these fibers (8). Production of force output via contraction of a localized group of muscle fibers that are forced to fire synchronously at a pre-selected rate would potentially reduce circulation to the exercising muscle. Direct stimulation of the sympathetic fibers supplying the intramuscular blood vessels has been shown to reduce blood flow to skeletal muscle in isolated muscle preparation (9). It is possible that reduction in muscle blood flow occurs in response to sympathetic fiber depolarization during electrical stimulation in the human subject. A reduction in oxygen supply secondary to local interruption in blood flow would shift energy production to anaerobic pathways. As a result of these factors, an earlier onset of fatigue would be expected and efficiency (work done/change in oxygen uptake above resting values) would be reduced.

The purpose of this study was to determine the efficiency of electrically evoked and volitional contraction of the human quadriceps muscle. It was hypothesized that the efficiency of electrically stimulated exercise would be lower than the efficiency of comparable voluntary exercise and that the penalties would be inversely related to the velocity and intensity of muscle contraction.

Greater understanding of the energetics of electrically stimulated exercise has immediate application to patient management. Although electrical stimulation with surface electrodes has been welcomed as a clinical tool to minimize the sequelae of muscle immobilization, to reduce deformity, and to augment strengthening of weak skeletal muscle, these clinical applications imply short term, therapeutic use of electrical stimulation. The use of electrical stimulation as a long-term substitute for voluntary muscle contraction would be practical if the relative energy demand, or efficiency, were to approach normal values.

Significant atrophy of all muscle fibers has been reported in spinal injury, head trauma and stroke (10,11). There is some agreement that complete lesion of the spinal cord in both animal and human subjects results in a significant increase in type II fibers and a decrease in type I fibers. The relative fiber type changes in hemiplegia are less clear. There is substantial evidence that prolonged electrical stimulation can shift the metabolic profile of muscle. Evidence for an increase in fiber diameter and force ouput of paralytic muscle is sparse.

The spinal injury, head trauma or stroke victim is not a ready-made candidate for electrically stimulated function. Preliminary evidence of greater oxygen uptake, ventilation and heart rate during electrically stimulated, concentric exercise in spinal injury patients when compared to normal subjects performing similar exercise has led investigators to conclude that electrically stimulated contractions are relatively inefficient (12).

METHODS

Twenty-three healthy subjects (x = 29.5 ±5.3 yrs) performed voluntary fatigue tests at 180, 120, 90 and 60°/sec. Isometric knee extension peak torque was measured and voluntary and electrically stimulated exercise was performed at 15, 25, and 33% of peak isokinetic torque. An isokinetic dynamometer (Cybex) was interfaced with a DEC-MINC 11/23 computer and a computer controlled stimulator (300 usec, symmetrical biphasic pulses) maintained the desired torque. Voluntary exercise was guided by a visual feedback display. Open circuit spirometry was employed for continuous sampling and analysis of expired gases.

Repeated measures ANOVA identified differences in fatigue characteristics associated with velocity as well as differences in efficiency due to velocity, intensity and mode of exercise. Paired t-tests (Bonferroni) were used for multiple comparisons. Correlation and regression analyses defined relationships between maximum voluntary effort, efficiency, respiratory exchange ratio, age and skinfold measurements. The significance level was set at $p \leq .05$.

RESULTS

The efficiency of electrically stimulated exercise was 35 to 114% less than that of matched voluntary effort at 60°/sec ($p<.001$) and 90°/sec ($p<.05$). Voluntary efficiency ranged from 10-57% versus electrically stimulated values from 4-44%. Efficiency was greater at the slower velocity ($p<.0001$) and highest intensity of effort in both exercise modes ($p<.01$) (Fig. 1).

The lack of differences in efficiency between exercise modes at 120°/sec may be attributed, in part, to variability among subjects in their perceived stress of and physiological responses to the test protocol. The major factor, however, appears to be the more anaerobic nature of the electrically induced exercise and the resultant overestimate of efficiency. The efficiency of electrically stimulated exercise may have been overestimated as a result of anaerobic metabolism.

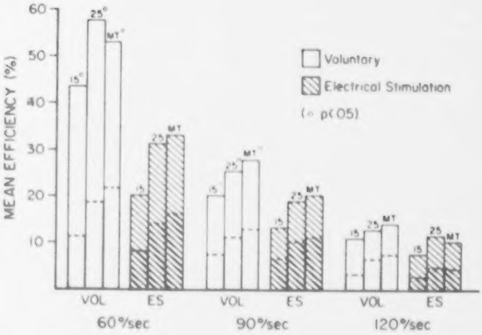

Fig. 1. ES versus VOL steady state efficiency with a correction for resting oxygen uptake. Shaded area portrays efficiency without correction for resting.

This conclusion is supported by the inverse relationship between efficiency of electrically stimulated exercise and extent of voluntary fatigue. Although men generated greater peak torque than women and had smaller skinfolds, there were no differences in tolerance to electrical stimulation or efficiency due to gender.

DISCUSSION

Interpretation of the differences between electrically stimulated and voluntary exercise identified in this study, is limited by the lack of measurement of: the location of the active muscle fibers within the quadriceps; the nature of the metabolic activity of those fibers; and the transient blood flow patterns to the contracting muscle. The relative change in efficiency among intensities and velocities of movement (in both exercise modes) may reflect some error in measurement of power output. This could be due to the lack of correction for gravity or the inability to do unloaded exercise with an estimate of apparent efficiency.

Despite these limitations, the findings of this study have immediate clinical application. Discomfort and fatigue were the major limiting factors in electrically stimulated force production. Isokinetic force production required greater stimulus amplitude and was less comfortable than electrically stimulated isometric contractions. Subjects were willing to tolerate 15-33% of their isokinetic voluntary maximum effort in contrast to 25-82% of their maximum voluntary isometric force output. Complaints of discomfort from patients asked to achieve 20-60% of normal force output, while moving against gravity, might be given more credence in light of these findings.

The artificial nature of surface electrical stimulation was further demonstrated by the similarities in maximal voluntary knee extension performance before and after complete, electrically induced fatigue of the quadriceps.

The reduced efficiency and relatively anaerobic nature of electrically stimulated exercise has relevance to both short-term therapeutic applications and long-term substitution for voluntary control of muscle. Although therapeutic electrical stimulation has specific clinical uses, it cannot be construed as equivalent to normal muscle contraction. Caution would appear to be warranted to avoid restriction of blood flow to muscle that is marginal in oxygen availability as a result of systemic or local pathology.

The extent to which fatigue resistance and efficiency of muscle contraction can be optimized is of clinical importance. This is especially true for the patient who requires chronic electrical stimulation for routine functional activities such as walking. Changes in the musculoskeletal system after spinal injury, head trauma or stroke would theoretically impose greater penalties on the efficiency of electrically stimulated muscle contraction than those observed in normal subjects. Future studies should be directed towards the determination of electrically stimulated exercise efficiency in patients with upper motor neuron disorders and the delineation of the extent to which electrode configuration, stimulus selection and conditioning can improve that efficiency.

CONCLUSIONS

1. The findings of this study indicate that submaximal, electrically stimulated exercise (at 60 and 90°/sec) is significantly less efficient than comparable voluntary effort.
2. It is proposed that the efficiency of electrically induced exercise was overestimated due to the metabolic pathways employed during electrical stimulation.

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RECRUITMENT DATA FOR NERVE CUFF AND EPIMYSIAL ELECTRODES

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ABSTRACT

Cuff and epimysial electrodes were chronically implanted in four cats. The cuff electrodes were placed around the left posterior tibial nerve, and the epimysial electrodes were placed on the right lateral gastrocnemius. After 3-4 months, the lead wires were explanted to determine recruitment data for all electrodes. It was found that 30-50 times as much charge was required with epimysial electrodes, however, the recruitment gain was much higher with cuff electrodes. Good control can be achieved with cuff electrodes with an amplitude resolution of .05 ma and a pulsewidth resolution of 1 μs.

INTRODUCTION

A number of independent efforts are currently underway to develop implantable multichannel stimulators for functional control of paralyzed extremities and bladders (1,2,3). These stimulators are to be used with a variety of electrodes, the selection dependent upon the particular nerves and muscles to be stimulated. The two most likely electrodes to be used for chronic implantation are cuff and epimysial electrodes.

The purpose of this study was to obtain recruitment data (muscle force versus stimulus pulse amplitude and width) for cuff and epimysial electrodes manufactured by Avery Laboratories. Both electrodes have been approved and used in humans, however, recruitment data for these electrodes were not available. These data are essential to establish design specifications for implantable stimulators to insure adequate controllability.

METHODS

The nerve cuff electrodes used in this study were 3 mm in diameter with three 1x2 mm platinum discs inside a silicone-rubber cuff. Electrodes were separated by 3 mm in the axial direction and were oriented every 120° around the nerve. For monopolar stimulation, the ground electrode was a 2 cm diameter, stainless-steel disc placed in the leg opposite to that being tested. When using the bipolar configuration, the two outer electrodes were used (6 mm separation), with the distal electrode cathodic. For the tripolar configuration, the center electrode was the cathode with the two outer electrodes shorted together to form the anode.

The epimysial electrode consisted of a 1x2 mm platinum disc adhered to a 1 cm diameter sheet of silicon-rubber reinforced with dacron. Stimulation was always monopolar using the stainless-steel disc as the anode.

Adult cats were anesthetized with 45 mg/kg pentabarbital given intraperitoneally. Throughout the surgery the animal's body temperature was maintained with a heating pad, and heart rate was monitored with an audio signal. The left popliteal fossa was exposed, and the cuff electrode was placed around the tibial nerve just below the bifurcation of the sciatic nerve. The right lateral gastrocnemius muscle was exposed and an epimysial electrode was sutured to the muscle under the distal extension of the biceps femoris muscle. Lead wires for both electrodes were passed subcutaneously to the lateral proximal thigh and coiled beneath the skin.

After 3-4 months the electrode leads were explanted to determine recruitment data for both electrodes. The animals were placed in a supportive frame with a transducer to measure the plantarflexion moment at the ankle. The pulsewidth of a compensated monophasic pulse was fixed at .01, .02, .05, 0.1, 0.2 or 0.35 ms and the pulse amplitude was varied to generate moments between threshold and maximal values. To prevent excessive fatigue, only twitches were produced, and the peak value of the resulting twitch was recorded.

RESULTS

A typical set of data for a monopolar cuff electrode is shown in Fig. 1. The normalized moment is plotted as a function of pulse amplitude for each pulsewidth. Values were read from these curves at moment levels of 10, 30, 50, 70 and 90% to generate the family of curves shown in the lower half of Fig. 2. A similar procedure was used to generate a family of curves for the epimysial electrode implanted in the opposite leg (upper half, Fig. 2). It is immediately apparent that 30-50 times as much charge was required with the epimysial electrode, and this result was consistent in all four animals.

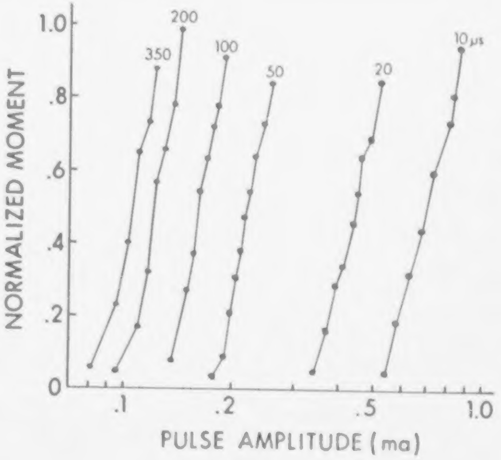

Figure 1.

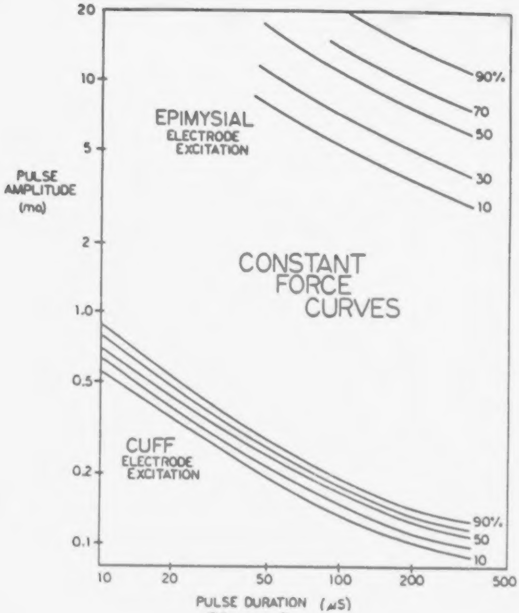

Figure 2.

Monopolar, bipolar and tripolar cuff configurations are compared in Fig. 3. Amplitude-width curves at 50% of the maximum moment are plotted for the three configurations. In all animals, monopolar stimulation required less charge per pulse at comparable output levels. Results with the bipolar and tripolar configurations were mixed.

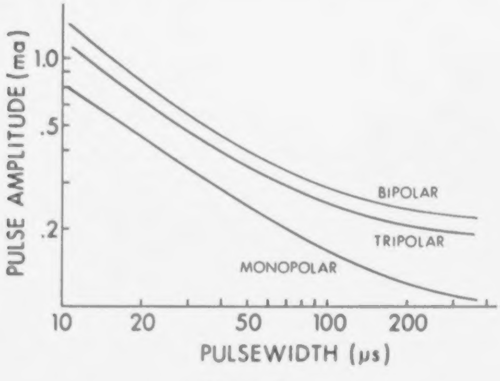

Figure 3.

Pulsewidth modulation is the preferred method for controlling muscle force (1,2). Recruitment curves for pulsewidth modulation can be obtained from Fig. 2 for any value of pulse amplitude, and this has been done in Fig. 4 for the monopolar cuff electrode. Curves are shown for 0.2, 0.25, 0.3 and 0.4 ma.

It is seen in Fig. 4 that the recruitment curves for pulsewidth modulation get steeper as pulse amplitude increases. The steeper the curve, the less control is available. It is therefore important that there be sufficient resolution in amplitude adjustment to insure adequate controllability. On the basis of these data and data from the other animals, the amplitude resolution should be at least .05 ma and pulsewidth resolution should be 1 s. These values guarantee that the greatest change in muscle force per control step would be 3% of the maximal muscle contraction.

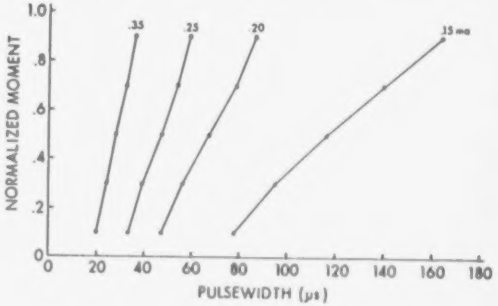

Figure 4.

DISCUSSION

The data shown in Fig. 1 for a monopolar cuff electrode are similar to those obtained by Gorman and Mortimer (4). At pulsewidths of 0.1 ms or greater, muscle forces are extremely sensitive to changes in pulse amplitude, with a .01 ma change causing muscle output to change by at least 10% of the maximal force. Adequate control of muscle force can be obtained with pulse amplitude modulation by using very short pulsewidths (.01-.02 ms) or by using pulsewidth modulation as shown in Fig. 4. In the latter case, the resolution for pulse amplitude should be at least .05 ma when using a pulsewidth resolution of 1 s.

The data on epimysial electrodes shown in Fig. 2 is consistent with results presented by Grandjean and Mortimer (5). They found that stimulus amplitudes were less than 1 ma when an epimysial electrode was placed near the location of nerve innervation, but were 2-20 ma when the electrode was placed on the side of the muscle opposite to the nerve entrance (which was the case in the present study). With the electrode placed near the nerve entrance, the controllability issues are similar to those previously described for the cuff electrode. When placed on the opposite side from the nerve entrance, the recruitment gains are low enough that controllability is not a major issue.

The finding that less charge is required with monopolar stimulation is consistent with previous results of McNeal and Bowman (6). The bipolar and tripolar configurations, however, have the advantage of reducing the current flow outside the cuff, thereby limiting the spread of current to nerves outside the cuff (6).

SUMMARY

To be compatible with nerve cuff and epimysial electrodes, electronic stimulators must produce pulses having adjustable amplitudes and durations over the ranges of 0.1-20.0 ma and 0.01-0.3 ms respectively. When using pulsewidth modulation, it is recommended that pulse amplitude resolution be 0.05 ma at the low end, and the resolution on pulsewidth be 1 μs over the entire range.

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TETANIC ENDURANCE AND TWITCH MOMENT OF ELECTRICALLY CONDITIONED PARALYZED MUSCLE

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ABSTRACT

One leg of each of 4 paraplegic persons was exercised for 8 weeks using electrical stimulation. Tetanic endurance and twitch moments of the exercised and unexercised legs were measured before exercise and at weekly intervals thereafter. At week 8 for 3 subjects, the moments at the end of 50 cycles of 1:1 s ON:OFF stimulation remained elevated by 3.0 to 7.5 standard deviations above the pre-exercise mean values. Twitch moments decreased by 50% after 1 week of exercise, then gradually increased. There were no changes in endurance or moments of the unexercised contralateral legs.

INTRODUCTION

Paralyzed musculature is sometimes electrically stimulated to improve strength and endurance for functional or therapeutic purposes. Stimulation systems to assist impaired gait of paralyzed individuals require conditioned musculature (1). Muscles of paralyzed persons have been conditioned following electrical exercise (2). Programs of electrical exercise to maximize strength and endurance gains are desired.

This paper describes the results of an electrical exercise program used during a companion study (3) addressing issues of open-loop control of the freely-swinging paralyzed leg. During the program, muscle moment and endurance of the quadriceps muscles were assessed at regular intervals.

METHODS

Exercise protocol

Four paraplegic persons with complete motor paralysis participated in an 8-week electrical exercise program. Their injury levels ranged from T7 to T12, and their times since injury ranged from 1 to 10 years. One quadriceps group was exercised (experimental leg, "E"); the contralateral group was not exercised (control leg, "C"). Subjects were instructed to exercise at home for up to 2 hours daily in any number of sessions never exceeding 1 hour per session.

Exercise was dynamic beginning with the knee in 60° of flexion and ending with extension to 20°. The UltraStim stimulator was used to exercise these muscles using 2 surface electrodes (4x9 cms). At least 3 weeks into the program, weights were added at the ankle in 0.5 or 1.0 lb increments to challenge the muscles further.

Rectangular biphasic current pulses of 300 us width were amplitude modulated at 30 pulses/s. During 1 cycle, the amplitude ramped from 0 mA to the maximum value in 4 s, held that value for 4 s, then ramped to 0 mA in 2 s followed by 10 s of rest. The subjects were instructed to adjust the maximum amplitude to maintain proper extension and to terminate a session when the leg failed to displace more than 10°.

Testing protocol

Twitch moment and tetanic endurance of the E and C legs were measured at weekly intervals. Baseline data were measured during 3 to 7 sessions.

Subjects sat in a chair fixing the hip and knee in 60° of flexion to permit isometric testing. A moment transducer developed in this lab was clamped to the lower leg. Muscle responses were sampled by a DEC MINC PDP 11/23 microcomputer.

The laboratory stimulator delivered constant current pulses from 0 to 110 mA at 30 pulses/s through 2 surface electrodes (4x9 cms) fixed on the anterior thigh (4). The frequency, pulse waveform, and pulse width were the same as those delivered by the home stimulator.

Muscle recruitment characteristics, the relationship of moment to stimulus amplitude, were measured using single pulses to minimize fatigue. Amplitude was increased from threshold to 110 mA in 10 mA increments.

For the endurance test, an amplitude was selected to generate 25 to 35% of the mean moment at 110 mA. This lower amplitude prevented damage to possibly osteoporotic bone during tetanic contractions (5). The endurance test consisted of 50 cycles of 1:1 s ON:OFF stimulation.

Muscle endurance and moment parameters

There were 1 moment and 3 endurance parameters. The mean peak twitch moment at 110 mA was "muscle moment (MM)". The steady-state moment during each endurance cycle was calculated by averaging the last .25 s of data. The parameters were: "endurance ratio (ER)", the ratio of moment at cycle 50 to the maximum moment; "endurance area (EA)", the moments normalized to the maximum moment averaged over 50 cycles; and "T50", the number of cycles to 50% of the maximum moment.

RESULTS

Exercise compliance

The weekly exercise times and muscle performance varied widely among the subjects. These times were 3.7, 9.2, 5.8, and 7.8 hours for RA, RM, DM, and KN, respectively. These subjects lifted 7.5, 5.5, 0.0, and 9.0 lbs at week 8, respectively.

Muscle endurance

Figure 1 shows the ER data for all subjects. To compare the ER values at week 8 with the pre-exercise values, the parameter improvements were compared to the pre-exercise standard deviation (SD) values. At week 8, the ER values improved by 3.0, 7.5, and 4.1 SD's above the pre-exercise mean values (PMV) for the E legs of RM, DM, and KN, respectively. The ER's for the E leg of RA and all C legs showed no improvement. The results for EA and T50 were similar to those of ER as shown in Table 1 (X_1(SD) is the pre-exercise mean and standard deviation. X_8 is the data value at week 8. ΔSD is the $(X_8-X_1)/SD$).

TABLE 1: ENDURANCE DATA

		Endurance Ratio			Endurance Area			T50		
		X_1 (SD)	X_8	ΔSD	X_1 (SD)	X_8	ΔSD	X_1(SD)	X_8	ΔSD
RM	E	0.31 (0.06)	0.48	3.0	0.60 (0.04)	0.70	2.5	31 (3)	39	2.6
	C	0.24 (0.05)	0.24	0	0.62 (0.04)	0.63	0.26	33 (3)	31	-0.7
DM	E	0.27 (0.03)	0.48	7.5	0.66 (0.03)	0.78	3.5	36 (5)	60	4.8
	C	0.19 (0.07)	0.17	-0.3	0.61 (0.04)	0.63	0.56	31 (5)	32	0.3
KN	E	0.22 (0.10)	0.61	4.1	0.64 (0.06)	0.78	2.2	34 (4)	>50	>4.0
	C	0.25 (0.10)	0.19	-0.4	0.62 (0.07)	0.64	0.29	32 (6)	33	0.2
RA	E	0.34 (0.05)	0.40	1.1	0.71 (0.02)	0.72	0.48	39 (3)	41	0.7
	C	0.36 (0.03)	0.22	-4.5	0.70 (0.03)	0.65	-1.5	39 (5)	34	-1.0

Muscle moment

The changes in MM, at 110 mA, with exercise are shown in Figure 2. The MM of E legs all decreased following 1 week of exercise by 3.0 to 3.2 SD's or 41 to 55% of the PMV's. During the next 7 weeks, these MM's slowly increased. No significant trends were observed in the MM's for the C legs.

DISCUSSION

The use of electrical stimulation to exercise paretic musculature has applications in the research and clinical environments. The daily electrical exercise program of the present study showed improvements in endurance of 4 paraplegic persons. No improvements in endurance were observed in the unexercised contralateral legs.

Muscle endurance

Improvements in muscle endurance began after 1 to 4 weeks of exercise in 3 subjects. The fourth subject, RA, showed no improvement in endurance, possibly due to the fewest exercise hours per week for RA compared to those for the other subjects. The exact mechanisms for improved endurance have not been documented in paralyzed people, but animal studies suggest that it is due to a conversion of fast-fatiguing muscle fibers to fatigue-resistant fibers (6).

The ER appeared to be the most useful measure of endurance. The ER demonstrated greater gains above the PMV's compared to those for the EA at week 8. Some T50 values could not be measured, since moments sometimes ended greater than 50% of maximum at the ends of the endurance tests.

Muscle moment

The most notable change in MM was the decrease of 50% of the pre-exercise values after 1 week of exercise for all subjects. One explanation for this could be that the exercise reduced the glycogen reserves in the muscles (7). Another mechanism could be the dynamic exercise modality. Isometric twitch strength can be increased with isometric exercise, and decreased with dynamic exercise (10).

Following the first week of exercise, the reduced MM's gradually increased towards their PMV's. Two studies reported decreases in muscle force following electrical exercise in animals (8),(9). One also reported some force increases (8). Both studies reported conversion of the exercised muscles to slow-contracting muscle which has less contractile force per unit area than fast-contracting muscle.

Moment and endurance parameter variability

Pre-exercise measurements could have been influenced by muscle reflexes, systemic changes, or electrode/motoneuron movement. Calculating the running mean data values and coefficients of variation from all C legs, it appeared that at

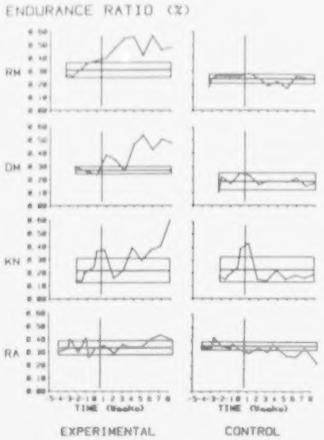

Figure 1: Endurance Ratio. Vertical lines mark beginning of exercise. Horizontal line and open bar are pre-exercise mean and standard deviation.

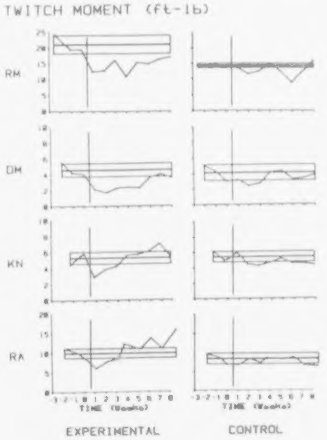

Figure 2: Muscle Moment. Vertical lines mark beginning of exercise. Horizontal line and open bar are pre-exercise mean and standard deviation.

least 5 sessions were required to provide an accurate estimate of the PMV's.

One study evaluated the variability of MM measurements over 3 days using surface stimulation of the quadriceps (11). They reported measurements were sometimes double or half those of the first sessions. These changes in the present study were 70 to 110%, less than the doubling or halving, but their findings support the need for more than 3 baseline sessions to estimate MM values.

The pre-exercise endurance parameters of KN followed a trend. The parameters of both legs of KN increased monotonically in similar patterns (Figure 1). Following the second week of exercise, all parameters decreased to initial values. Perhaps systemic changes influenced her muscle responses. No trends were observed with the other subjects (all male).

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Epimysial Electrical Stimulation:
Short-term Therapeutic Applications

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ABSTRACT

This report describes a clinical program in which electrical stimulation via surgically placed electrodes is combined with routine surgical intervention and physical therapy. The electrodes are surgically fixed to the epimysium and the leads directed subcutaneously to exit the skin at a common site. The clinical rationale for placement of electrodes and the stimulation protocol are presented and responses to stimulation in the first three implant patients described. Preliminary results indicate that functional muscle contractions of the deep hip muscles can be obtained with epimysial electrodes. Stimulation with surface electrodes alone has not produced a useful muscle response. These results have immediate application to short-term therapeutic intervention for patients with upper motor neuron disorders. Encouragement is also provided for future clinical use of implanted stimulation systems.

INTRODUCTION

Electrical stimulation has been shown to be an effective clinical tool to activate skeletal muscle in patients who have muscular weakness due to immobilization or upper motor neuron disorder. Stimulation with surface electrodes has not, in our experience, provided functional hip control. Surface electrical stimulation is limited by the superficial field of current density, discomfort, and the lack of selectivity of muscle activation.

The purpose of this report is to describe the preliminary results of a clinical program in which electrical stimulation by epimysial electrodes is combined with routine surgical intervention and physical therapy. Six patients with head trauma, stroke or spinal injury have received epimysial electrodes to augment hip and knee stability for stance or to improve limb advancement.

BACKGROUND

The patient with spinal injury, head trauma or stroke suffers both muscle atrophy and a change in the relative fiber type distribution of the involved muscles (1,2). There is substantial evidence that prolonged electrical stimulation can change the metabolic profile of muscle and improve endurance in electrically stimulated exercise (3,4). Muscle fiber diameter was increased in head trauma patients with long standing knee contractures (5). Quantitative documentation of improvement in force output of paralytic muscle is, however, minimal (3).

The relative inaccessibility of deep muscles to surface stimulation has spurred attempts to control the hip via implanted devices. Orthotic substitution is available at the ankle (AFO) and at the knee (KAFO), but there is no satisfactory remedy for inadequate hip control. Energetic analysis of spinal injury patients who walk with orthotic assistance has further demonstrated the enormous metabolic demands of ambulation. The demands were significantly less in patients who walked with one free knee when compared to patients who walked in bilateral KAFO's (6). In light of these findings, selective activation of the quadriceps and biceps femoris (short head) is warranted to eliminate the knee orthosis.

Electrical stimulation has the potential to improve walking in stroke, head trauma and incomplete spinal injury patients as a result of increased muscle force output and more appropriate timing of muscle contraction.

METHODS

Candidates for epimysial electrodes were sought from the patient population at Rancho Los Amigos Medical Center. Those selected demonstrated deficits in hip and/or knee control that could be improved by stimulation of the muscles crossing the respective joints. In addition to a routine physical therapy evaluation, assessment included electrodiagnostic studies to determine innervation status and kinesiological electromyography to identify the temporal nature of the response of both target muscles and their antagonists.

Titanium electrodes, approximately 1 cm in diameter and 4 mm thick, with a silastic backing, were sutured to the epimysium after intraoperative identification of the most excitable location on the muscle surface. The insulated stainless steel leads were directed subcutaneously to exit the skin in a common site. The leads were enclosed in a connector for communication with a commercially available stimulator.

The stimulation program was begun two weeks after electrode implantation. Patients received two hours of stimulation per day. Initially the stimulation was cycled for 30 minute periods. A duty cycle of 1:3 on/off was used until the muscle maintained a functional contraction for the full 30 minutes. The off time was then gradually reduced. A compensated monophasic waveform of 300 usec duration was provided by the Medtronic's Respond II stimulator. When the patient could assume the upright position the stimulation was triggered according to weight transfer from one leg the other during exercise encouraging reciprocal lower limb use, supported standing, and upright balance training with an instrumented feedback device (7). Stimulation became an integral part of therapy with the goal of independent standing transfers and walking.

Bimonthly documentation of impedance, stimulus threshold to palpation, maximum current tolerated, isometric force output and decrement in force output over a 10 minute stimulation period was performed in a laboratory setting. Walking ability was recorded by instrumented footswitches and ambulatory aids.

RESULTS

Six patients (3 with stroke, 1 with head trauma and 2 with incomplete spinal injury) have received epimysial electrodes. All 6 have electrodes on the gluteus medius for hip stability; 5 have electrodes on either the gluteus maximus or adductor magnus, or both, for hip extension; 3 have implants on the short head of the biceps femoris to augment knee flexion; 3 have electrodes on either the iliacus or sartorius for hip flexion; and 2 have electrodes on the quadriceps for knee extension. Two patients underwent a tendo-achilles lengthening and one had an anterior obturator neurectomy at the time of electrode placement.

Three of the patients are new to the program. The first 3 patients have been on a stimulation program for 3 to 5 months. Patient 1 was brain damaged in an automobile accident 1.5 years prior to admission to the program. He was unable to take a step due to hip instability on his hemiparetic side. Patient 2 suffered a stroke 10 years ago at age 25 years. He collapsed at the hip during single limb stance, and had not walked since his stroke. Patient 3 suffered a stroke, at 25 years of age, 4 months prior to epimysial implantation. He lacked both hip stability and limb advancement.

Improvement in the gluteus medius, implanted in all 3 patients, is depicted in Figures 1 and 2.

Electrically stimulated and voluntary moments improved over the 3 to 5 months of therapy. Surface stimulation produced minimal contractions when compared to epimysial activation in the same test session (Table 1).

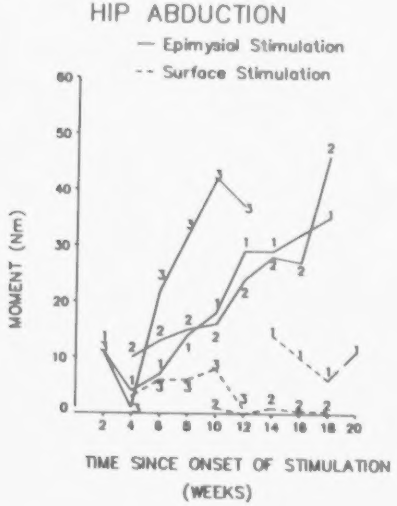

Fig. 1. Electrically stimulated hip abduction moment. Patients 1, 2 and 3.

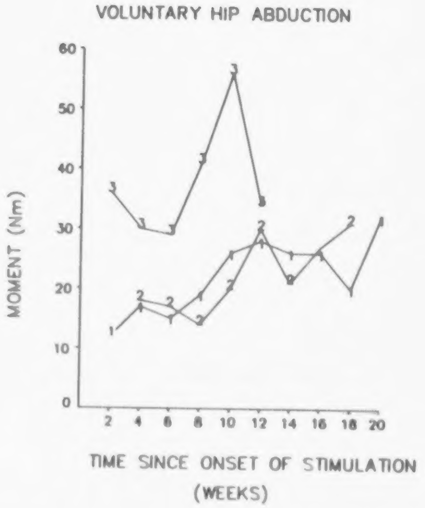

Fig. 2. Maximum voluntary hip abduction moment. Patients 1, 2 and 3.

Hip extension moments improved in a similar fashion (Table 1). The adductor magnus was stimulated in 2 patients and the gluteus maximus was activated in the remaining patient. Surface stimulation again produced only minimal moments.

Table 1. Range of Improvement in Hip Moments After 3-5 Months of Stimulation. (n=3)

	Electrical Stimulation		Voluntary
	Epimysial	Surface	
Abduction:			
Absolute Δ(Nm)	30-36	0-5	12-20
Percent Δ	250-360	0-160	55-159
Extension:			
Absolute Δ(Nm)	14-28	0-5	19-62
Percent Δ	200-700	0-50	48-1900

Patient 3 remains unable to voluntarily bend his involved knee. Epimysial stimulation of the biceps femoris (short head) has produced a knee flexion moment of 12 Nm. Simultaneous epimysial stimulation of his sartorius did not prove to be useful to augment hip and knee flexion for swing due to inadvertent quadriceps stimulation.

Threshold and the maximum tolerated amplitude varied with the proximity of the epimysial electrode to nerve. Intra-individual impedance measurements changed little in contrast to the more variable threshold and maximum comfortable amplitude (Table 2). Endurance ratios (end/initial moment) improved modestly (23-66%) over the stimulation period. There has been no evidence of infection or internal lead breakage.

Table 2. Stimulation Characteristics of Epimysial Electrodes

	Gluteus Medius N=3	Gluteus Maximus N=1	Adductor Magnus N=2	Biceps Femoris (short head) N=1
Threshold (ma)	9–33	10–39		
	6–19		1–3	
	1–8		1–2	4–7
Maximum Amplitude Tolerated (ma)	25–41	30–54		
	30–48		20–43	
	8–13		11–15	17–25
Amplitude above Threshold (ma)	7–13	6–22		
	23–30		19–41	
	1–12		9–14	12–21
Impedance (ohms)	350–480	230–350		
	240–480		350–440	
	210–410		370–480	430–500

All three patients have achieved the ability to walk independently with the use of ankle-foot orthoses and ambulatory aids. Patient 1 walks at 14% of normal velocity. He triggers the stimulation by a fingerswitch attached to his walker. Patient 2 walks with a hemi-cane. His velocity is slow, 5 m/min, but he can manage household chores such as cooking and cleaning in the standing position. After 4 months he elected to discontinue the stimulation during walking but he continues to stimulate during exercise. Patient 3 walked independently with a standard cane by the third month after stimulation was initiated. He triggered stimulation with a footswitch until the fourth month when he discontinued stimulation during walking because of gadget intolerance and improved volitional function. He no longer uses a wheelchair and is independent in all community activities including travel on the municipal bus. His velocity is approximately 30% of normal.

DISCUSSION

The improvements observed in these three patients cannot be credited to electrical stimulation, spontaneous recovery, surgical intervention or physical therapy alone. It does appear, however, that the electrical stimulation has influenced the speed of recovery.

These preliminary results demonstrate the feasibility of obtaining selective, functional contractions of deep muscles with epimysial electrodes. The lack of infection and relative consistency of electrical measurements imply stability of the electrode system.

Elicitation of reflexive limb flexion or provision of sensory cues does not mandate a strong stimulus. Greater stimulus charge is required to generate a muscle contraction capable of supporting the body during single limb support. Maximum electrically evoked hip abduction ranged from 32 to 42% of normal values (8,9) in these first 3 patients. Electrically stimulated hip extension approximated 20% of reported normal values (8). These percentages would be equivalent to a Fair to Fair+ manual muscle test grade (10).

The patient who does not have adequate return of volitional control could benefit from the electrically stimulated forces observed during epimysial stimulation. The ability to subcutaneously connect the existing epimysial leads to an implanted stimulator would allow the future patient to progress from short-term therapeutic stimulation to a more permanent substitution for inadequate voluntary control.

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A MAN/MACHINE INTERFACE FOR CONTROL OF AN UPPER EXTREMITY FUNCTIONAL NEUROMUSCULAR STIMULATION SYSTEM

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ABSTRACT

A neural prosthetic hand system employing Functional Neuromuscular Stimulation to provide hand prehension and release has been developed for individuals with a high level spinal cord injury. The man/machine interface consists of various transducers which measure command signals generated by the user's remaining voluntary function. These command signals are processed by a supervisory control algorithm which provides the user with a means of controlling coordinated hand function as well as providing feedback of the operating state of the system to the user through remaining sensory sites.

INTRODUCTION

Functional Neuromuscular Stimulation (FNS) has been used to provide control of hand function in C5, C6 level quadriplegia (1,2). Both laboratory based systems (3) and portable systems (4) have been developed and in use by our center for at least ten years. A functional block diagram of our FNS hand system is presented in Figure 1. The input(s) to the system are commands generated by the user from some remaining voluntary function. These input commands are transduced by various transducer systems and are both proportional and discrete in nature.

The input processor is responsible for the processing of the transduced input commands. This can range from simple gain and filtering to realization of nonlinear input/output transfer functions. These processed input commands are used as inputs to the supervisory control algorithm which provides the user with a quick and convenient means of controlling the grasp function realized by the FNS system. The control scheme utilized in the neural prosthetic hand system provides the user with the mechanisms to turn the stimulation on and off, to select one of several predefined hand grasp patterns, to control the grasp pattern in a continuous proportional manner, and to lock the proportional command at any desired level. The supervisory control algorithm is responsible for control of the machine operating state and state transition of the FNS system. It is also responsible for the feedback of the machine state to the user.

The output(s) of the control algorithm are used as the input to the stimulus parameter modulator. The modulator coordinates and regulates multiple channels of stimulus waveform parameters. The output of the stimulus parameter modulator is used by the stimulator outputs to produce graded coordinated muscular movement and/or sensibility. The stimulus outputs can be either external, for stimulation through chronically indwelling percutaneous electrodes, or generated by a totally implantable stimulator (5).

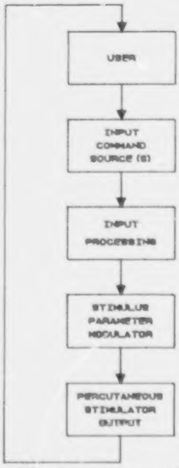


Figure 1. Block Diagram of the FNS System

MAN/MACHINE INTERFACE

As shown in the block diagram, input(s) to the neural prosthetic hand system are derived from the user's remaining voluntary function. The higher the level of injury the lower the number of available command sites. While we have developed a number of switch controlled hand systems utilizing both mechanical switches and processed EMG signals, proportional commands used to control the operating point of the hand grasp provide the user with a real time interactive interface.

In the case of spinal cord injury, individuals with injury levels as high as C4 retain some degree of shoulder motion. The concept of shoulder position as a proportional command source has been around for some time (6,7) and more recently studied in detail as a control source for neural prosthetic hand systems (8). A miniature two orthogonal axis proportional position transducer measures the scapular movement of the shoulder. The shoulder position transducer body is mounted to a small plate. The plate slips into a small leather pad which is attached to the user's chest with double sided adhesive tape. A position sensing arm extends from the transducer's body and a mounting pad at its end is secured to the shoulder with tape. The outputs of the transducer are proportional to shoulder elevation/depression and protraction/retraction, relative to the sternum.

CONTROL OF FNS SYSTEM

Switch inputs are derived from body and/or wheelchair mounted switches. Typically a pushbutton switch with a two inch diameter activating surface is attached to the same chest mounting plate as the shoulder position transducer body.

The user is provided with feedback from the neural prosthetic hand system in various ways. There is visual feedback and sometimes low level proprioception from the synthesized hand grasp itself. The user is also provided with machine operating state information through audio cuing and/or sensory stimulation of dermatome retaining normal sensation (9). Visual displays are inappropriate because they distract the user visually from performing his task.

CONTROL SCHEME

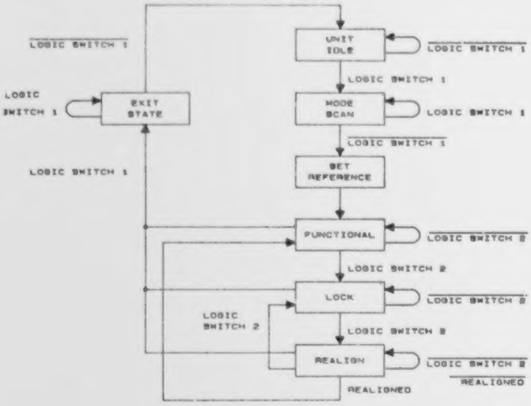
An appropriate control scheme should allow the user to control his grasp function in a quick and convenient manner. Functional neuromuscular stimulation is used to provide or augment two basic hand grasping patterns, palmer prehension and release (three jaw chuck) and lateral prehension and release (key grip) in quadriplegic subjects with a lesion at the C5 or C6 level. Both of these grasping patterns are realized using as many as six separate electrodes for each pattern. It would be impossible for the user to control such a multidegree of freedom system directly, especially with the limited number of inputs available. As indicated earlier, the stimulus parameter modulator provides the coordination of the resultant hand grasping pattern. The investigators determine the appropriate multichannel input/output relationship using the computer based laboratory stimulation system (3). Typically the modulator maps a single proportional input command to the stimulus parameters (pulse width and interpulse interval) for each of the muscles in each grasping pattern. The result is a single proportional command which controls the operating point of the hand grasp.

The supervisory control algorithm relates the transduced and processed user input commands to the single proportional input used to control the stimulus parameter modulator. The user typically controls the FNS system through one proportional command source and several logical command sources. The proportional command is used to control the operating point of the hand grasp. The logical commands are used to control the machine operating state of the system. The proportional command is typically derived from either protraction/retraction or elevation/depression of the shoulder contralateral to the controlled hand. Logical commands may be derived from further processing of the shoulder movement, from body or wheelchair mounted switches, or a combination of these sources.

The supervisory control algorithm also generates the appropriate form of feedback indicating to the user the machine operating state and machine state transitions of the FNS system. This typically is in the form of pitch and duration modulated audio tones and/or frequency and duration modulated sensory stimulation.

EXAMPLES

We have implemented several man/machine interface/control schemes for the control of our neural prosthetic hand system. These control schemes are represented by the generalized state diagram given in Figure 2. The operating states of the system include: the system active/idle state which turns the stimulation on and off, the grasp mode selection state which allows the user to select one of several hand grasping patterns, the proportional command set point which defines the operating range of the proportional input command, the lock state which maintains the proportional command at some fixed level, and the unlock state which again re-enables the proportional command.


UNIT IDLE
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LOGIC SWITCH 1
EXIT STATE
MODE SCAN
LOGIC SWITCH 1
$\overline{\text{LOGIC SWITCH 1}}$
LOGIC SWITCH 1
SET REFERENCE
FUNCTIONAL
$\overline{\text{LOGIC SWITCH 2}}$
LOGIC SWITCH 2
LOCK
$\overline{\text{LOGIC SWITCH 2}}$
LOGIC SWITCH 2
LOGIC SWITCH 2
REALIGN
$\overline{\text{LOGIC SWITCH 2}}$
$\overline{\text{REALIGNED}}$
REALIGNED

Figure 2. State Diagram.

The most widely used control scheme derives the logical switch 1 command from the chest mounted pushbutton. Activation of this switch causes the system to move from the non-stimulating idle state to the mode selection state. Mode selection is accomplished by a scanning technique. Audio cues (one or two short tones) indicate which of the grasping patterns will be activated; releasing the chest switch stops the scanning in the desired grasp mode. A short delay allows the user to position his shoulder at the set point he desires, after which the system turns on in a proportional control state with the setpoint representing a minimum hand grasp operating point (typically full extension). Audio tones indicate the state change to the user. Shoulder movements from the setpoint proportionally control the selected hand grasp.

The logic switch 2 is derived from processing of the orthogonal axis of the shoulder transducer to detect velocities exceeding that of a preset threshold for a given period of time.

Rapid movement of the shoulder orthogonal to the proportional control axis initiates a lock state, in which the proportional command is maintained independent of further shoulder movements. An audio tone indicates the transition.

For this control scheme, logic switch 3 is generated in the same manner as logic switch 2. This causes a transition into the unlock state. Another audio tone indicates to the user the state change. For this example, in order to exit the unlock state, the user must realign the proportional command to be equal to the command level when the lock state was initiated. Again an audio cue indicates the transition back to the proportional control state. This provides a smooth transition from the lock state without disrupting the grasp.

To place the system into the idle state, the user need only to depress and release the chest mounted switch. This particular control strategy has been in use in portable FNS systems in the field in excess of five years with good acceptance by the users.

We have used variations of this control scheme, most notably the use of sensory stimulation for feedback of operating state and state transitions. Sensory feedback is also used to indicate the operating point of the proportional command signal. In certain individuals (weak C5's) we have noted problems in the use of velocity detection to initiate the lock state (logic switch 2) due primarily to crosstalk between velocity and postural position.

We are currently evaluating a technique in which the logic switch 2 signal (transition into the lock state) is derived from inactivity of the proportional command source for some period of time proportional to the magnitude of the previous activity. This effectively implements an anticipated or automatic lock. Unlocking the grasp (logic switch 3) is still accomplished using velocity detection when cross talk is not a problem since the proportional command is held constant.

We have also implemented variations in how the setpoint is defined when regaining proportional control from the lock state. This provides the user with the ability to redefine his setpoint without having to go back to the idle state.

Work is currently under way in enhancing the mode selection algorithm to make it more dynamic.

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Special Interest Group 11

Computer Applications

Chair: David L. Jaffe, M.S.E.

PREFACE TO THE SYMPOSIUM ON APPLICATIONS OF SHAPE-RECOGNITION TECHNOLOGY IN REHABILITATION ENGINEERING

Robert Mills, Session Organizer
Electronic Industries Foundation

ABSTRACT OF SYMPOSIUM

Shape-recognition technology has numerous promising applications for the mass market, as well as for people with disabilities. Consider, for example, optical character recognition (OCR) systems for reading documents, guidance systems for robots, sensory aids for persons with visual impairments, and shape measurement tools for fitting orthotic devices. Some of this technology is commercially available now, but improved devices are being developed.

This Scientific Symposium is intended to promote the flow of leading-edge shape-recognition technology to applications which help meet the needs of people with disabilities. Three experts working on state-of-the-art shape-recognition systems at industrial laboratories will describe their projects, and will consider with us applications of that technology in our field. A rehabilitation engineer will discuss the applications of shape-recognition technology for assistive devices. An important part of the Symposium will be the discussions between the panelists and the audience at the end of the session.

WHAT IS SHAPE-RECOGNITION TECHNOLOGY?

Shape-recognition technology is a generic term for systems which (a) sense information about the shape and position (and possibly other characteristics) of nearby objects using appropriate devices, (b) process that information, and (c) present the results in a useful form to humans or to other machines.

The sensing components can be active or passive devices. Sonar is an example of an active sensory device. Machine vision in ambient light is an example of a passive sensory device which produces images of surrounding objects.

The extraction of useful information from the sensed data generally requires information processing. For example, the recognition of a letter or a word on a sheet of paper requires a pattern recognition process. The detection of motion by a robot could involve rapid comparisons by an image processor of subsequent images. Information processing usually requires fairly hefty computing capacity, especially if it is to be done in real time. For that reason, dedicated special purpose computers are often needed, sometimes using parallel processing.

The type of system output depends, of course, on the purpose of the shape-recognition technology. If, for example, the system is an OCR reading machine, then the output could be fed into a speech synthesis device. If the system is a sensory aid for a visually impaired person, then the output information must be presented in representations which the human can comprehend quickly, using nonvisual senses.

Technically, machines capable of shape recognition have not been easy to develop. David Marr, late of the MIT Artificial Intelligence Laboratory, pointed out in his book, Vision - A Computational Investigation into the Human Representation and Processing of Visual Information, that as recently as in the 1960's, almost no one realized that the problems were so difficult. The reason for this misperception, Marr suggested, is that humans are so good at using vision for shape-recognition.

THE SYMPOSIUM PROGRAM

Despite the technical difficulties, many now realize that shape-recognition technology has numerous promising applications for mass-marketed devices, for defense and space, and for helping to meet the needs of people with disabilities. The subject therefore is appropriate for this RESNA Technical Symposium. The strategy here is to bring together a few people who are expert in recent advances of shape-recognition technology (but who are not necessarily expert in rehabilitation applications) with people who are interested in possible applications of shape-recognition technology for assistive devices.

The Symposium presenters will be:

Peter M. Steven, Senior Software Engineer from Kurzweil Computer Products. He will discuss the latest advances in OCR reading machines, which obviously have utility for persons with visual impairments.

Robert Douglas, Program Manager for the DoD Autonomous Land Vehicle Program from Martin Marietta Aerospace. He will discuss development of a vehicle designed to detect obstacles in its path and maneuver around them. He also will consider with us possible application of this technology to robots designed to maneuver in a room with a person having a severe physical disability.

Randy Luck from Aspex, Inc., the developers of an image processor known as PIPE. He will discuss applications of image processors in, for example, defense and space. He also will consider possible application of image processors in a sensory aid system for visually impaired persons.

Guy Hammer, Associate Director for Technical Evaluation at the Veteran Administration's Rehabilitation R&D Evaluation Unit. He will discuss applications of shape-recognition technology in rehabilitation engineering, including CAD/CAM shape measurement tools for fitting orthotic devices.

The Symposium will end with a round table discussion between the presenters and with the audience. In past Symposiums of this type which focused on other subjects, this discussion period was an important part of the program.

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PROBLEMS OF AND REQUIREMENTS FOR CHARACTER RECOGNITION SYSTEMS

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ABSTRACT

The current state of font-independent character recognition is discussed with a brief review of a recent publication in the area. Though much progress has been made several major classes of problems still exist. The ability of people to handle these problems so effortlessly suggests that current approaches may be inadequate or inappropriate. Nevertheless an accurate recognizer is only part of a character recognition tool which must include features making the recognizer usable over a wide range of material.

INTRODUCTION

Font-independent character recognition has been a topic in computer science and artificial intelligence for more than twenty years. The potential usefulness of fast, accurate character recognition, especially for the visually impaired, is clear. Numerous academic and commercial efforts have sought to develop character recognition machines, several resulting in marketed products.

However character recognition by itself is only one part of a reading system. One must incorporate the character recognition package in a larger recognition system capable of identifying and avoiding graphics; discerning differing text formats and layouts; and presenting the recognized material in a predictable and ordered form. For this paper, I will review the current state of font-independent character recognition, the major problems which remain, and the design requirements for an effective character recognition tool.

CURRENT RESEARCH

At first thought it might seem that character recognition, although not necessarily simple, should be relatively straightforward. Each character has clear features which differentiate it from other characters. The research project might only entail collecting data about the character images and compiling tables associating some set of features with a character. This is in fact how most researchers initially approach character recognition. It is a good starting place, but to date only represents a partial solution.

In a recent article appearing in the IEEE Transactions on Pattern Analysis and Machine Intelligence, Simon Kahan, Theo Pavlidis, and Henry S. Baird presented the findings of their research into font-independent character recognition.[1] They suggested reducing the character image to a set of stokes (see Fig. 1). The pattern of strokes is then matched against known patterns for each character, with the closest match yielding a character guess.

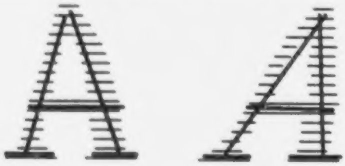

Fig. 1.

The first drawback the authors noted was that some characters had very similar stroke patterns. For example, O, o, 0, D, and Q all shared essentially the same stroke pattern. This was also true of 6 and b, or b and h if the bottom of the h were closed, or a, e, s, g, 8, and B with two closed loops. A secondary recognizer needed to be added to improve identification in these ambiguous cases.

When it came to testing their recognition algorithms, we were told that multipart characters, such as i, j, :, ;, !, etc., could not be recognized because their process works with a single connected image. Additionally the authors suggested that "a few confusions were inevitable and had been forgiven:"[2]

0 O	zero and oh
1 l I	one, el, and eye
9 g	nine and gee

C / c O / o S / s U / u V / v W / w X / x Z / z

When trained on a single font, recognition of 10 point characters was near 100 percent. When training with six fonts, the recognition rate dropped to about 97 percent. That means that one could expect 60-90 errors per page, not included the multipart characters and confusion cases noted above. A good typist would be expected to have only a couple of errors per page. Such recognition levels are inadequate for a useful recognition tool, and yet in many ways this work represents the state of the art.

PROBLEMS IN CHARACTER RECOGNITION

Why is it that computers with their great speed and power are unable to do work people do almost effortlessly? Possibly the human recognizer is looking for different features, and what research must uncover is the exact set of feature to employ for character recognition. But more likely, the human recognizer approaches character recognition in an entirely different manner.

The two most difficult and common problems in character recognition are touching characters and broken characters. If an r and an n touch, the resulting image looks very much like an m. Similarly when an r and an i touch they look like an n. While two touching G's resemble nothing recognizable at all. The problem for broken characters is effectively the same: the images of a broken character could easily be mistaken as images of other characters. The underlying problem being that even if the machine knew how to break touching characters and how to combine broken characters, it is almost impossible to know when an image needs to be broken or merged.

Yet these are two things human recognizers handle very easily (see Fig. 2). We infer connectivity in broken images, such as the IBM logo; and break points in connected images, such as the RESNA logo. No character recognition system yet imagined could correctly recognize these images.

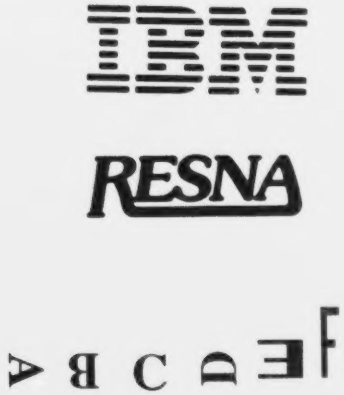

Fig. 2.

We can also stretch, twist, and rotate images in ways that could never be easily described to a machine. It's not just that we can stretch and rotate images, for machines could do that, it's that we know when to use these transformations. The challenge for artificial intelligence systems, including character recognizers, has always been can we discover how humans do what they do, and not simply to mimic human results.

Font-independent character recognition is certainly not at this level of sophistication. Character recognition systems depend on constraining the recognition problem to well formed solid images in a single orientation and within known size boundaries. Many systems expect only text, and fail if pictures are included. Low-end systems usually require the document be in a single font specified from a short list of fonts known to the recognition system.

Even with these constraints, the images of different characters are frequently very similar, as was described by Kahan, Pavlidis, and Baird. In some fonts, images are not only similar, they are identical. On many typewriters the lower case L is also used is a one. In san serif fonts upper case I, lower case L, one, and the stem of a lower case I are all identical. And in an italics san serif font, these all look like slashes.

To make machines better general recognizers, they need greater intelligence, specifically some understanding of context. The problem of contextual understanding arises over and over in artificial intelligence, but thus far there has no sufficiently powerful approach to yield any general insights. Rather programmers tend to take a more pragmatic approach looking for contextual clues which can aid understanding, but avoiding anything more than a minimal functional understanding. Many character recognition systems use dictionaries to confirm character guess, but no one attempts to "read" sentences to see if they make sense.

The Kurzweil Reading Machine has long know of the need for multiple character recognition techniques. Using our system on a clean, well-printed page, we have realized recognition over 99 percent accurate. Kurzweil continues to focus on increasing the range of materials that can be handled. In a commericial recognition device, the accuracy requirements are frequently in the range of 99.8 to 99.95 percent correct. The Kurzweil Data Entry Machine allows the computer to tap the wisdom of its human operator, by verifying guesses the computer consdiered questionable. After such training, the Data Entry Machine can often reach the levels accuracy needed.

DESIGNING A RECOGNITION TOOL

In order to make a character recognition tool, one needs more than just a font-independent character recognizer. Identifying all the letters on a printed page is only the beginning. Words must be correctly formed, ordered into sentences, mindful of multiple columns, all while avoid pictures and graphics.

Character recognition itself may not be to the point. If the recognition rate is fairly good, any character recognizer could be useful for a blind or visually impaired individual. Rather it is the complete system capable of understanding page layout, identifying text regions, and presenting them in an easily controlled format makes the character recognition system a useful tool. It is the ability to handle a wide variety of documents that makes it a practical system.

What is said here about character recognition applies equally well to other machine-aided recognition systems. A visually-based object recognition system is of little use if the objects must always appear in isolation. It's one thing to recognize a cup in a laboratory setting, it's altogether something else to recognize it in a kitchen cabinet. No matter how promising the initial experiments with recognition of objects in the lab, the development of a useful device requires robustness, making the system usable in a range of environments.

ACKNOWLEDGMENTS

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IMAGE PROCESSING AND IMAGE UNDERSTANDING

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Aspex Incorporated

ABSTRACT

This paper will present the basic concepts of image processing and image understanding. The types of hardware systems used for image processing and image understanding will also be discussed.

INTRODUCTION

Image processing and image understanding are fields that have grown tremendously in the last ten years. Some of the key application areas in both research and practice include:

- Guidance of robot arms in manufacturing systems.
- Automatic inspection in the food processing, electronics, and automotive industries.
- Autonomous vehicle guidance for farm vehicles, industrial mobile robots, and military AGV's.
- Enhancement and automatic interpretation of satelite imagery.
- Medical image processing such as CT, NMR, real-time ultrasound, and cine-angiography.

What is image processing and what is image understanding? To answer this we must first know what vision is. Vision is the process of seeing and knowing what and where objects are in a space, using images. It involves acquiring these images, processing them and finally making decisions.

Image processing is the the set of techniques used to alter or enhance an image (typically a television image) so that some set of qualities or features may be made visible to a human observer.

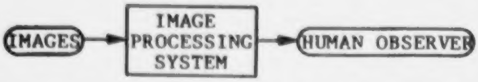


Image processing system block diagram.

Image understanding is the process of developing a description of an image in order to make decisions about its contents. It uses the techniques of image processing to extract features from a scene and then some sort of decision is made about the scene. An image understanding system is a system that integrates image processing and automatic decision making.

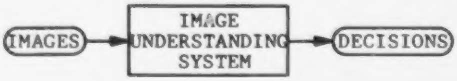


Image understanding system block diagram.

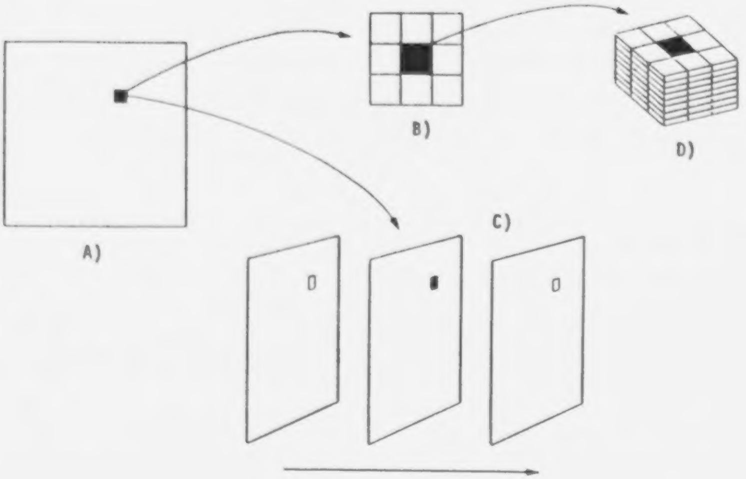
TECHNIQUES OF IMAGE PROCESSING

There are four major ways of processing images for real-time feature extraction. The first is as isolated points, the second is as a spatial neighborhood, the third is as a sequence of images and the fourth is as Boolean bit plane images.

Point processing operates on each pixel in the image identically without regard to the surrounding spatial or sequential neighbors. Single valued point processing produces an output that is an arbitrary function of one input. Two valued point processing produces an output that is a function of two inputs. Both of these types of point processing involve simple modification of the image gray scale.

Spatial neighborhood processing produces an output that is an arithmetic function of the input pixel and its eight neighbors. This is typically done as a 3 x 3 sum of products arithmetic convolution and is done identically for all locations in the image. This is used to extract spatial edge features and lines from the images.

Sequence processing is the capability of processing multiple images as a set. These multiple image sets are often sequences over time but they could be sets of some other property such as chromaticity, stereo right and left pairs or multi-resolution pyramids. Sequence processing is typically used for extracting motion features from a scene.



Fundamental image processing operators.
(A) point (B) spatial (C) sequence
(D) Boolean

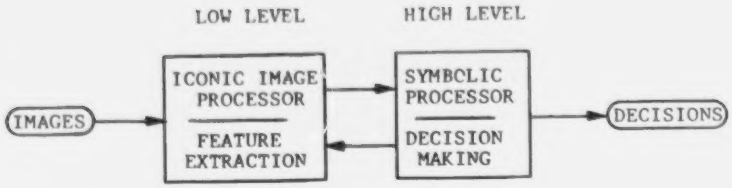
Boolean processing is the processing of images whose pixels are either ones or zeroes. An 8 bit stack of these images could comprise a feature vector where each bit represented the presence or absence of some particular property or feature at that point in the original image. Neighborhood operations can be done in a Boolean mode to further process the features.

A fifth image processing technique is geometric processing. This is not typically used in feature extraction but it can be very useful for changing the representation of an image for presentation to the user. Geometric processing involves altering the spatial properties of the image as if the image were were printed on a rubber sheet. The sheet can then be shrunk or stretched in different ways for many useful effects.

IMAGE UNDERSTANDING

Image understanding is partitioned into what are called low and high level vision tasks. Low level vision is performed on "iconic" images, that is images arrayed in an X,Y pixel space much like a television image. Low level vision performs extraction of simple features such as edges, lines, motion and depth from the images. One of the goals of low level vision is to produce an image made up of feature vectors. That is, for every pixel location, the pixel value represents not a gray scale but the presence or absence of a set of such features. These low level tasks are very regular and involve a tremendous amount of information processing. Because of this regularity, a parallel processor is ideally suited for this task.

The high level vision tasks are the ones that determine the relationships between the various features found with low level vision and make decisions about the scene based on these relationships. High level vision is usually performed on what are called "symbolic" images, that is representations of the scene based on the observed features. The high level task performs recognition of objects, their attributes and relationships and interpretation of these relationships. This classification process is inherently far less regular and involves much testing and matching with a priori models that anticipate what might be in the images. High speed serial computers provide the most flexibility and are currently used for this task.



An image understanding system

HARDWARE

The low level image processing and feature extraction tasks involve processing a tremendous amount of data in real-time. Typical processing rates are usually on the order of 10,000,000 to 10,000,000,000 calculations per second. Because of this, and because the image format is very regular, some sort of special purpose parallel hardware processor is used. Some examples of hardware processors include:

- PIPE - Aspex
- WARP - Carnegie Mellon University
- Image processing boards - Datacube, Imaging Tech, etc.
- Image processing systems - Vicom, Gould, etc.

The high level decision tasks are much less regular. They involve much testing, matching, branching. Because of this, more conventional serial computers may be used although there are presently several parallel computers that may also be used. Some examples include:

- LISP machines - Symbolics, Texas Instruments, etc.
- Connection Machine - Thinking Machines
- Butterfly - BBN Computers
- Sun-3 - Sun Microsystems
- Hypercubes - Intel, NCubed, etc.

A real time image understanding system can be built using a hardware processor for low level feature extraction and a computer for the high level symbolic description and decision making process.

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THE FUTURE OF SEEING-EYE ROBOTS IN REHABILITATION ENGINEERING

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ABSTRACT

A prospective technology assessment is made of some necessary conditions for useful applications of robotic guidance systems, machine vision based sensory aids, optical character recognition based information systems, computer assisted design/computer assisted manufacturing (CAD/CAM) and related high technology systems in rehabilitation engineering. Now considered "premature" orphan devices with regard to rehabilitation engineering, machine vision technologies need intensive care incubation in a more favorable market and high tech support environment prior to adoption by the rehabilitation engineering community. Looking beyond engineering feasibility to the issues of safety and liability, inherently safe seeing-eye robots of advanced designs will be limited to demonstrations for the near future because of economics and institutional inertia. New technological advances depend as much upon the ability to obtain investment capital and develop a sound operating and maintenance organization as they do on scientific revelations and engineering.

INTRODUCTION

Perhaps a definition of the use of the word "future" in the title of this paper may help to give some perspective. It is not a billion years from now when we may have moved awayfrom the planet earth, nor a million years from now when the remaining population of earth may be trying to resurrect the scientific method of inquiry. At the present rate of robotic development a thousand years from now we will have intelligent robot companions that can not only move, see, hear, talk and feel, but that will also be able to communicate, educate, analyze, work, protect and, in the eyes of the artificial intelligence (AI) chauvinists, think for us. But for the purposes of this paper the future is one hundred years away (plus or minus 50).

TECHNOLOGY TRENDS

There are several trends in robotics R & D and product commercialization which will have an impact on rehabilitation engineering. The development of sensory capabilities will result in a large growth area for manipulation and observation robots which can replace people in jobs that are routine and often boring. Another area of significance is off-line programming, potentially linked to a CAD/CAM system. Research is being done on adaptive control systems for robots. Also, more advanced safety systems are being developed to enable a human to work "alongside" a robot. The first ANSI standards have been developed for industrial robots (but specifically exclude personal and medical robots) which have begun to set the tone of conditions of acceptance of robots by society. At present, the paramount safety principle is to keep people out of the envelope of operation of the robot except for maintenance and repair under special circumstances. This is in diametric opposition to most needs for robotics in rehabilitation engineering.

PERCEPTION TRENDS

Called "people amplifying appliances" by the non-engineering community, high tech devices have been emerging steadily throughout the eighties. Such appliances are perceived to be "ethnotronic" or culture-bearing electronic systems, capable of machine/human and machine/machine interaction. Not surprisingly there is often "rehabilitation resistance" by the disabled user to wholesale acceptance of these technological solutions proposed by the rehabilitation engineering research community. Among the many definitions of appropriate technology is the human community view that as people work together they must use technology that they can understand and manage. It is possible that at least half of the disabled users of high technology do not understand or know how to manage their high technology systems and would prefer low technology solutions. Here the synergism of system science, value-oriented discourse and technology assessment emerges. A sober appraisal of past prospective technology assessment studies and their impact on the rehabilitation engineering delivery community is needed. Realistic forecasts, scenarios, etc. are needed and the relationship between evaluation and public policy regarding rehabilitation engineering needs to be clarified.

ROBOTIC GUIDANCE SYSTEMS

The concept of breeder robots, robots building more robots, (or robotic procreation) has fascinated many science fiction readers for years. The critical missing link to this breeder robot system is the vision system necessary to provide feedback for real time motion control rather than motion planning (1).

The Electronic Industries Association (EIA) has contributed significantly to the future of breeder robots by standardization of almost all commonly used electronics components for industrial robots. Recently EIA addressed inductor standardization - the last major problem area. An especially flexible robot is now on the market that handles up to 6,000 components per hour with placement accuracy ensured by a visual system that checks for recognition of circuit board patterns (2). Economical inspection of interconnection quality after soldering remains a pressing problem. This is especially important in the case of military projects, in which the speed and accuracy of inspection must be guaranteed. Most military specifications allow visual (human) inspection of no more than two joints per second. Robotic guidance systems will become feasible with maturity of vision systems.

A high-speed machine vision system designed for the security market has just gone into production (3). This system can identify shapes in real time and is expected to be able to perform face identification. It employs high speed processing, achieved by eliminating the software interface for processing information. Since there is no software to be interrogated, matching of binary image templates can be done as fast as the video camera can transmit the data to the template matcher. Now considered "premature" orphan devices with regard to rehabilitation engineering, machine vision technologies need intensive care incubation in a more favorable market and high tech support environment, such as the military or NASA, prior to adoption by the rehabilitation engineering community.

SENSORY AIDS

A need exists for an inherently safe three-dimensional vision compensation system for blind mobility. Robert Mann separated the components of vision deficient mobility into three functions: 1) the blind person's next step, 2) his directional orientation and 3) his navigation along reasonably long travel paths on both familiar and unfamiliar terrain (4). In order for machine vision systems to properly compensate for natural vision deficit, they must warn the blind person of danger only when danger is present and otherwise not distract the persons attention from other potential cues through their remaining senses. This supervisory systems design concept is very similar to traveling with a guide dog or seeing-eye robot (5). When this task has been accomplished, however, there remains the problem of optimal coding and display of the required acquired information. Guide dogs are now available, equipped with three dimensional vision, have non-volatile memory, can travel safely and reliably over long distances on familiar terrain, require simple maintenance, cost little to operate, provide warning and protection and serve as companions for life. The remaining need, therefore, is the ability to navigate in unfamiliar terrain and in an inherently safe manner. The remaining question is, however, how much would this cost?

OPTICAL CHARACTER RECOGNITION

The application of optical character recognition based automated reading machines for the blind has met with serious problems. 1) the number of blind persons interested in using such a system has been greatly overestimated. The result of this market shortfall has been that the price for later models rose significantly rather than decline as had been forecast. 2) the cost of maintenance of the units in the field was far beyond the expected costs of repair for technology in similar but broader applications. 3) although omni-font recognition has reached the point of reading virtually all common letter quality type fonts, more recently, with the proliferation of personal computers and copiers, the quality of character required to be read is draft quality dot matrix printer output or a poor quality multi-generation photocopy.

These systems will come into widespread use as rehabilitation engineering tools only when they have been adopted by the business community as cost-effective tools.

PROSTHESES/ORTHOSES AND CAD/CAM

At present, the design of prostheses/orthoses is by rule of thumb and artisanal expertise while production is done by labor-intensive hand fabrication. To alleviate the production bottleneck, it will be necessary to diminish the inefficiencies and inconsistencies inherent in manual craft. This requires systematic application of new measurement, design and manufacturing technologies, which have already been developed, resulting in automating the provision of mobility aids. Burgess and Boone have called it Automated Fabrication of Mobility Aids (AFMA) (6).

The need is to produce appropriate orthopedic shoes, prostheses (artificial limbs), orthoses (orthopedic braces) and expert system prescription for mobility aids. Shape sensing, tissue analysis and shape manipulation are the three essential components of this automated system. Shape sensing certainly could be performed in the future by machine vision. Shape manipulation is within existing CAD/CAM system capabilities. The problem of tissue analysis remains to be solved. Possibly, it might be done with the use of simultaneous three-dimensional positron emission tomography (PET) type metabolic activity overlay mapping of nuclear magnetic resonance (NMR) type imaged physical structures in conjunction with an expert robot with a sense of touch and feel. There are favorable factors supporting the widespread adoption of CAD/CAM in prosthetics in the future: 1) The market already exists and will continue to grow. 2) There is a shortage of skilled artisanal expertise with a further projected decline. 3) Cost efficiencies exist over the existing methods as long as the emphasis is on cost-effectiveness rather than on elaborate technological solutions.

CONCLUSION

The future of machine vision technologies in rehabilitation engineering will depend on many factors. The amount of capital available will determine if anything is done at all. The degree to which the rehabilitation engineering community expresses its desire to adopt each application of the technology will determine its ultimate availability for use by disabled people. At a minimum there will need to be a rehabilitation engineer champion for each particular technology application since most of these are orphan devices and will not be cost effective/justified (7). But, in the final analysis, the user (the disabled person) not the engineer, will determine the future of seeing-eye robots in rehabilitation. New technological advances depend as much upon the ability to obtain investment capital and develop a sound operating and maintenance organization as they do on scientific revelations and engineering. Looking beyond engineering feasibility to the issues of safety and liability, inherently safe seeing-eye robots of advanced designs will be limited to demonstrations for the near future because of economics and institutional inertia. Communication should be established, however, between rehabilitation engineers and the design engineers now working on these technologies to allow the maximum opportunity to influence arbitrary design parameters in favor of the needs of the disabled user at the point of first decision, and at no cost, rather than to wait until the production models are rolling off of the assembly line.

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The expressed opinions presented here are those of the author and do not necessarily represent policy of the Veterans Administration

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THE DEVELOPMENT OF A MICROELECTRONIC AXON PROCESSOR SILICON CHIP NEUROPROSTHESIS

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ABSTRACT

The major limitation of peripheral nerve repair has been the matching of specific axon-to-axon connections to re-establish correct communication channels within the peripheral nervous system following the transection of a nerve. The purpose of this project is the development of a microelectronic silicon chip neuroprosthesis for nerve repair at the axon level that would enable specific axon-to-axon connections. This would require the development of an implantable silicon chip (1 by 1 millimeter in size) with a matrix of addressable axon tubes such that severed axons could regenerate through the tubes. Several of these chips stacked in sequence can act as a micro-switchboard to identify and control regenerated axon-to-axon communication. By electronically connecting the correct proximal and distal ends of the microchip axon tubes, input and output information in the repaired peripheral nerve can be directed to the proper channels, thus effecting a nervous system repair at the axon level.

INTRODUCTION

Nerve injuries complicate successful rehabilitation more than any other form of trauma. The hand in particular functions poorly when sensory and motor functions are impaired. Self-care and other tasks of daily life can be severely impaired because of lack of tactile discrimination and motor dysfunction. Patients may suffer additional injury such as trophic skin ulcers and unrecognized burns when protective sensibility is diminished. Painful neuroma formation, often more disabling than its associated sensory deficits, commonly causes major disability. Long-term disability places enormous burdens on the patient, his family, and society.

A primary cause of incomplete recovery of function after nerve injuries, even with successful regeneration of axons across the repair site, is that regenerated axons rarely reconnect to the original motor end-plate or specialized sensory cell. A neuroprosthesis (nerve chip) which can intercept misdirected afferent and efferent nerve impulses and reroute them into the appropriate channels, would provide increased recovery of function and helping to alleviate the burdens of long term disability. The nerve chip could also serve many other functions as a man/machine interface, with applications to functional electrical stimulation in spinal cord injury cases and prosthesis control for many areas of the body.

BACKGROUND

The following is a brief summary of prior research by others in this area. A number of investigators have experimented with implantable nerve recording devices using semiconductor materials, though not necessarily using active electronics on the implant. In 1969, Marks reported on a pioneering experiment in which bullfrog axons were grown through holes in an implanted plate [1]. In 1973, Llinas, Nicholson and Johnson [2] proposed an implantable monolithic wafer used as a recording electrode for neurophysiology studies. The following year Mannard, Stein and Charles [3] published recordings from peripheral nerve fibers which had regenerated through an implanted electrode in freely moving amphibians. A theoretical and mathematical study of tubular electrode arrays intended for chronic, multiple single-unit recording from captured nerve fibers by Loeb, Marks and Beatty appeared in 1977 [4]. In 1980, Edell published his Ph.D. thesis on the development of a chronic neuroelectric interface which recorded from rabbit nerves grown through slits in an implanted electrode, and later reported on further progress with this technique [5,6].

So far as is known, this project is the first to propose the use of a microelectronic implant as an active link in redirecting neural signal transmission. [7]

EXPERIMENTAL WORK TO DATE

Preliminary experiments with these elements have lent some support to the ideas outlined in this proposal. In its current stage of development, the nerve coupler is cast from polyglycolic acid (PGA) or fabricated from polycarbonate (Lexan). It includes a central housing with a transverse slit that both supports the silicon chip and allows access to its edges for eventual electrical connections. The housing has two opposed axial tubular extensions 1mm in internal diameter to contain the ends of the transected nerve. The nerve ends are not inserted directly in the coupler, but into telescoping PGA tubes that slide into the coupler extensions. The tubes support the nerve without play and allow reasonably precise alignment of the nerve ends within the coupler.

688

Preliminary hole-array chips (without microelectrode structures) were made from single crystal N-type silicon and fabricated with standard semiconductor industry techniques into chips with dimensions of 1 mm^2 by 100 µm in thickness. The hole grids were drilled with a CO_2 laser mounted on a computer-controlled stage. A 50 by 50 array of holes with an entrance diameter of 25µm and exit diameter of 50 µm was fabricated. The chips were inserted in the couplers and implanted between the severed ends of peroneal nerves in rats. Nerve regeneration was assessed at 1, 6 and 13 months. The 1-month animals showed histological regeneration of the axons through the chip axon holes. The 6-month animals showed histological and physiological regeneration through the silicon axon holes, including remyelination. There were multiple axons within each tube at 6 months. In the 13-month animals, there were far fewer axons per hole, increased axon diameter (up to 8 µm), and increased thickness of myelination

Subsequent refinements make it possible to drill more cylindrical holes with entrance and exit diameters of 8 µm, approximating the average diameter of a typical peripheral nerve axon. Preliminary animal studies show axons regenerated through these holes with myelination.

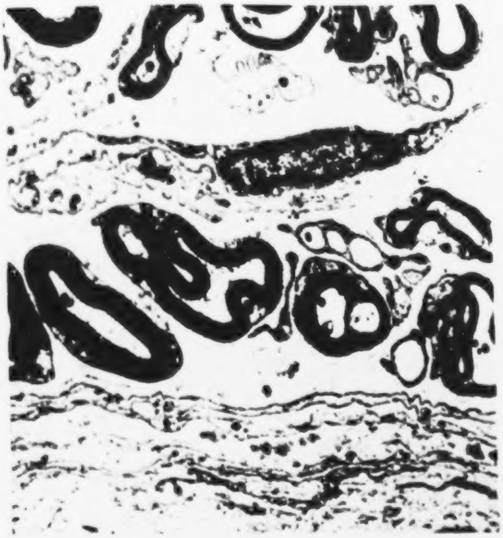

Figure 1: Electron Micrograph showing regenerated axons grown through a chip.
(Magnification x4500)

FUTURE WORK

Further development and refinement of the nerve coupler is planned . The future nerve coupler will snap together and also simplify the introduction of the nerve chip. We are presently trying to establish the optimum microenvironment conditions for regeneration in the nerve. These conditions or nerve growth factors will be used to improve nerve regeneration through the nerve chip.

Design and fabrication of a passive nerve chip. A major step towards the realization of a clinically usefull nerve chip is the development of a passive microelectrode array. An important reason for developing such an array is to prove the long term viability and biocompatibility of the novel semiconductor fabrication techniques under development for this project. In order to test these properties, a series of long term *in vivo* tests will be required, with careful histological assessment of possible tissue reactions as well. *In vitro* accelerated life tests will be carried out to verify that the devices will have relatively long useful lifetime required of a permanent neuroprosthesis. Another reason for development of the passive array is for testing the different microelectrode geometries under development and determine the optimum surface area for recording and stimulation. A mathematical working model of the actual behavior of the microelectrode will be observed and is a necessary prerequisite to the model required in order to optimize the design of the active electronics which cannot be "over-designed" due to extreme limitations of size. These limitations are due to the requirement to fit the active circuitry to access thousands of axons within the cross-sectional area of the nerve itself. In order to test and characterize arrays of large numbers of through-holes for axons, an automated test system is being designed and implemented. With this equipment the large data sets required to fully characterize the microelectrodes both pre- and post- implant will be obtained until with relative ease. Extremely accurate characterization of the microelectrode is particularly important for detection of trends indicating performance decay which may present as only slight variations over the course of the implant experiment, thus this data may point to areas requiring longer-term studies.

CONCLUSIONS

This neuroprosthesis when completed would act as an implantable micro-switchboard which would have several potential applications in addition to peripheral nerve repair. It could help to partially restore nervous function in spinal cord injury patients by connecting peripheral nerves above the injury site to peripheral nerves below the injury site. It could also act as a man machine interface to directly couple peripheral nerves to bioprostheses such as an artificial arm or hand for the upper extremity amputee.

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ALTERNATIVE ACCESS METHODS FOR THE IBM FAMILY OF PERSONAL COMPUTERS AND TRUE COMPATIBLES

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ABSTRACT

The PC A.I.D. and PC Serial A.I.D. are examples of recent developments in accessing alternatives for IBM personal computers(PC/XT/AT and Jr.) and true compatibles. These two devices provide a range of alternative input methods, including one-finger typist keyboard mode, regular, step and inverse scanning methods, single and dual switch Morse Code and connection of alternative (expanded) keyboards. The PC A.I.D. connects to the printer port of the computer, and provides all switch input methods. The PC Serial A.I.D. provides switch input methods, and also allows the use of alternate (expanded) keyboards. Both allow the standard keyboard to be used in one-finger typist mode. Transparent, memory-resident software drives the devices and provides the user with help screens of features and commands, which can be called up within application programs using any input method. The software also allows key re-definition, variations in scan line position and width, and the ability to change device parameters from any input method. Utility programs provided with the devices allow users to customize the software for their specific needs by individualizing scan arrays, modifying the Morse Code assignments, editing key re-definitions and configuring alternative keyboard layouts.

INTRODUCTION

DADA Designing Aids for Disabled Adults is a non-profit organization devoted to developing low cost technical aids for disabled persons, and to providing educational services to health care professionals, persons with disabilities, and the general public. Technical problems faced by persons with disabilities who are in or entering the workforce are a primary focus of our research and development efforts. A well recognized and major problem has been the lack of a variety of alternative access methods for the IBM and IBM compatible microcomputers that predominate in the business world. This has resulted in the restriction of career opportunities for those adults whose disabilities prevent them from using the typical computer keyboard as an input device. DADA felt that it was important to provide IBM PC users with the range of access methods that are available to Apple IIe computer users via the Adaptive Firmware Card, developed by Adaptive Peripherals, Inc. Maintaining compatibility in terminology with the AFC, as well as in function, was viewed as essential both for the end-user and for the educator or clinician.

DESIGN GOALS

1) To provide a variety of input methods for the IBM family of personal computers and compatibles at low cost.
2) To provide a device that could be used with a portable computer in school and office settings.
3) To allow user access to a wide range of available software.
4) To make it possible for the disabled person to use the computer with minimal or no assistance.
5) To emulate the functions and configuration methods of the Adaptive Firmware Card so that clinicians could easily transfer knowledge between computers, at the same time making use of the capabilities of the MS-DOS computers.
6) To allow easy installation of the hardware and software with few or no changes to the target system.
7) To design a flexible software shell that could be easily expanded to allow new input methods or design changes in the future.

METHODOLOGY

The design goals of portability and ease of installation were met by keeping the hardware components as compact as possible. Multiple input methods, low cost, transparency, flexibility, compatibility with the Adaptive Firmware Card and elimination of the need for user assistance were achieved by creating a predominantly software product. The PC A.I.D., which provides switch input functions through use of the parallel port simply uses minimal decoding hardware to decipher the key hits. The PC Serial A.I.D. requires more extensive hardware logic to determine key selection on alternate keyboards.

Provision of separate input devices allowed a lower cost alternative for those users or facilities not requiring access to the alternate keyboard input methods. The parallel port was selected as it comes standard with most computer systems.

Both products make use of a new keyboard interrupt routine which interprets the switch or keyboard input from either the parallel or serial port and sends the required key information to the computer. When the program is loaded, it changes the interrupt vector to point to the new routine instead of the original BIOS routine and loads the new keyboard routine. This routine remains resident in computer memory while application programs are running. The original interrupt vector is restored on exit from the pcaid or seraid program.

Access to system functions and an on-line help facility provided within each input method allows maximum independence in use of the computer. Used in conjunction with an AUTOEXEC.BAT file, the emulation software and application program can be loaded atuomatically when the computer is turned on.

DESCRIPTION

Hardware

The PC Serial A.I.D. is a small box that is cabled to the serial port of the computer. A 12-volt AC adapter unit is provided and the unit may also be run off a 9-volt rechargeable battery. Alternative keyboards and/or one or two switches connect to the PC Serial A.I.D. The PC A.I.D. unit plugs into the computer's parallel port; a printer may be plugged into the back of the PC A.I.D. One or two switches of the user's choice may be plugged into labelled switch connectors on the unit.

Input Methods

The PC A.I.D. and PC Serial A.I.D. provide three scanning methods:

- regular, in which the cursor moves automatically across the scan line and selection occurs when the switch is activated,
- inverse, in which the cursor moves when the switch is activated and selection occurs when the switch is released, and
- step, in which the cursor moves once in response to each switch activation and selection is caused by a delay.

Single and dual switch Morse Code methods are provided, with auto-keying available when using two-switch Morse Code. Default files for Scanning and Morse Code are provided with the software.

Assisted Keyboard (one-finger typist) adds sequential key access for multiple key commands(e.g., control-alt-delete), as well as keyboard redefinition, when using the regular computer keyboard.

If only the Assisted Keyboard method is required, PC Assisted Keyboard is available in software only; no additional hardware is required.

In addition to the above methods available with both devices, the PC Serial A.I.D provides two Alternative (Expanded) keyboard methods, a key configuration that substitutes for the regular keyboard and a Phraseboard configuration for use with the Unicorn keyboard as a communication board. Default configuration files are provided for the Unicorn, King and Mini keyboards.

Systems Functions
The software includes the ability to access a number of systems functions from either the DOS, or from within a software application. The on-line Help facility, the ability to make changes in input method and rate and key redefinition are available to users of all methods except the phraseboard configuration of the alternative keyboard. Scanning users are able to turn off the sound that accompanies cursor movement, change the location of the scan line from the bottom to the top of the screen depending on the screen format of their application package, and change the width of the scan line between 40 and 80 columns. Alternate scan array sets can be loaded at any time. Morse Code users may vary the length and frequency of the feedback tone, and load alternate code definition files. When using the alternative keyboard, users may turn off the key-hit feedback tone if desired.

Instant Message Creation (Key Redefinition)
Any key may be redefined within an application to create macros or to allow one key access to a frequently used word or phrase. Messages may contain up to 60 characters, and this can be extended by nesting the redefinitions. The keyboard state may be changed between the redefinition state and normal keyboard state by a toggle switch included in the systems functions. Key redefinition files may be saved to or loaded from the disk at any time, from DOS or within an application package.

Exiting PC A.I.D or PC Serial A.I.D
After leaving the application program, the keyboard may be restored to its normal state by selecting the highest numbered input method option shown under the change input method system function, method 6 for the PC A.I.D. , 9 for the PC Serial A.I.D. and 2 for the PC Assisted Keyboard.

Utilities
A modular stand alone utility program is provided to enable customization of the various input methods according to the needs of the individual user or to provide more efficient use of a specific software package. Up to 10 interlocking lines of scanning arrays may be created and/or edited using the Scan-Create module. The systems function lines are additional to the 10 definable lines, and although they cannot be reconfigured, the user may establish branches to them. Message or key redefinition files may be created or edited using the Message-Create module, including files created and saved using the instant message option of the PC A.I.D. or PC Serial A.I.D. The standard Morse Code sequences may be assigned to other keys, if desired, by using the Morse Code Redefinition module. The keyboard configuration modules may be used to configure any alternative keyboard with an 8x16 or smaller matrix in a keyboard format, i.e., establishing a key to key correspondence between the alternative keyboard and the regular keyboard. The Unicorn keyboard may also be configured in a variety of phraseboard layouts, ranging from 2 1/2-keyboard sized keys to the maximum 128 keys, for use as a communication tool. In this mode, up to 60 characters may be displayed with each key hit.

EVALUATIONS

The PC A.I.D. and PC Serial A.I.D. have been evaluated at over twenty hospital and university facilities in North America. A list of contact names is available from DADA. Reception of the products has been extremely positive and a number of the suggestions received have already been incorporated in new software releases.

DISCUSSION

The PC A.I.D. and PC Serial A.I.D. software are able to run successfully on more than a dozen IBM-compatible computers, and with many text-oriented software applications. Developers at DADA are currently working on problems that interfere with the use of the scanning methods when running the devices with some graphics-oriented software packages.

Another area of some concern is whether the amount of memory utilized by the transparent software, although not substantial (34k), might cause problems when using the system with large application programs on low-memory computers. Currently the software for all input methods is loaded into the computer's memory when using the device(s). Software changes are being made that will result in only user-specific information being stored in memory. These modifications are scheduled for completion by the time of publication.

Running several transparent programs at the same time can potentially cause problems if these programs access the same interrupt vectors. Early versions of the PC A.I.D. and PC Serial A.I.D. software did not work with several of the popular desktop accessory packages that are commercially available. These incompatibilities were resolved in later versions of the software, but may continue to cause problems with new and future commercial packages. Until some universal standardization is implemented in the design of transparent software packages, the only safeguard designers have is to test with existing software packages.

The PC A.I.D. and PC Serial A.I.D. have been accepted as useful products for persons whose mobility impairments prevent use of the standard computer keyboard. Developers at DADA are currently working on additional input methods that may be used with the existing products. These include an oculo-encephalographic input mode, and a screen keyboard that can be accessed with a 'mouse' - switch combination.

ACKNOWLEDGMENTS

DADA wishes to acknowledge the support and funding received from the Applied Technology Unit of the Ontario Ministry of Community and Social Services during the development phase of the PC A.I.D. and PC Serial A.I.D. We also wish to thank International Business Machines Corporation which loaned the equipment used in developing the devices.

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IMPACT OF STANDARDS ON FUTURE ENVIRONMENTAL CONTROL SYSTEMS

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ABSTRACT

Home control systems being developed for the mass-market may have a particularly favorable impact for disabled and elderly consumers. If future mass-market demand allows economies of scale not now possible for the environmental control systems used by disabled persons, then improvements in cost, variety of devices, and support services can be expected. To achieve broad compatibility, representatives of the home appliance industry and other interested parties, working in an Electronic Industries Association (EIA) Committee, are developing voluntary Consumer Electronic Bus (CEBus) Standards. When promulgated, devices marked "CEBus Compatible" can be plugged into any CEBus home system, and used with other CEBus compatible devices. But will the CEBus Standards take into consideration the special needs of people with disabilities?

INTRODUCTION

Environmental control systems offer a degree of personal independence to people with severe physical disabilities by enabling them to operate electronic and electrical devices in the home (hereafter referred to simply as appliances). Using sip and puff switches or other types of special devices, people with high level spinal cord injuries or neuromuscular disorders are able to operate appliances such as lamps, TVs, air conditioners, telephones and electric beds with little or no help.

Electronic home communication and control systems which resemble environmental control systems are also being developed for the mass market. These mass market systems are called "home control systems", or "smart home systems", or sometimes "home bus systems". Here the word "bus" means one or more pathways, such as electrical conductors, used for transmitting signals or power from one or more sources to one or more destinations.

If mass-market demand for home control systems becomes large enough to allow economies of scale not now possible in the production and marketing of environmental control systems, then improvements in costs, variety of devices, and support services can be expected. Home control systems may well be one of the fortuitous cases where technology developed for the mass-market promises to have a particularly favorable impact for disabled and elderly consumers. But again, for this to happen, economies of scale in the mass market will have to be achieved.

Consumer acceptance, and thus potential mass-market demand for home control systems will be greater if various system components can function with a variety of other devices, including those made by competing manufacturers. To make this broad compatibility possible, representatives from the consumer electronics industry and other interested parties, working in an Electronic Industries Association (EIA) Committee, are developing voluntary Consumer Electronic Bus Standards. The term "Consumer Electronic Bus", abbreviated as "CEBus", means technology which complies with the requirements of these EIA Standards.

This paper discusses the impact home control systems, and particularly the CEBus Standards are likely to have on the rehabilitation community.

WHAT ARE HOME CONTROL SYSTEMS?

Inexpensive microchips built into appliances make remote control of home appliances technically easy from any location inside or outside the home. Home control systems are electronic communication and control systems connected to appropriate home appliances. The systems serve as intelligent "electronic maids and butlers", with microchips built into the appliances and/or in central computers giving the systems their intelligence. In most cases, users are not aware they are using microchips or computers.

Consider some of the possibilities for home control systems in, for example, the bathroom. Ms. Consumer can fill her bathtub with water controlled to her favorite temperature, either automatically or upon instructions given over the phone from her office. If it's dark outside when she takes her bath, the drapes are closed over the windows, but the room lights aren't dimmed until she is settled in the tub. If the doorbell rings, she can switch the bathroom TV to the front door monitor. Using the voice recognition system, she can dispense a check for the paperboy into the mailbox at the front door, and then thank him over the intercom for his services. If the phone rings, the system turns off the whirlpool-action and the TV sound so she can take the call in the bath. Suppose a storm causes the power to fail. The system, which has battery backup, knows she is in the bathroom, and turns on the battery powered lamps in that room. When the power comes back on, the system resets all the clocks in the house.

Home control systems can be built today for these, and more mundane tasks. Some skeptics believe home control systems are gadgets which will have little utility after their novelty disappears. However, a number of manufacturers and marketers are betting that consumers will find solid utility in them, and that home control systems eventually will enjoy a broad-based mass market demand.

Home control systems, as well as environmental control systems, can be considered to have four components. This particular division of the systems into components will help to make a point later in the paper:

1) The User-Interface Components, which are the components utilized directly by the user to tell the system what to do, and to be aware of what the system is doing. Voice recognition devices and display monitors are examples of user-interface components.

2) The Controlled Appliances, which are electronic and electrical devices capable of receiving and responding to the control system's signals to accomplish a desired task.

3) The Controller Unit or Units, which contain the microchips that do the "thinking" for the system, and have the system logic stored in them.

4) The Transmission Media, which are the information-transfer links or pathways interconnecting the other components.

Six types of transmission media are utilized in home control systems:

- power lines,
- twisted pair cables,
- coaxial cables,
- fiber optic cables,
- radio frequency carriers, and
- infra-red carriers.

Each of the media has its advantages and disadvantages, as suggested in Table 1. For example, the power line medium has good installation characteristics because existing house wiring can be used. Dedicated cables offer protection from outside interference, and good privacy. Radio-frequency and infra-red media are good where portability is needed, as in

Table 1
COMPARISON OF MEDIA CHARACTERISTICS

	Power Line	Twisted Pair Cable	Coaxial Cable	Fiber-Optic Cable	Radio-Freq. Carrier	Infra-Red Carrier
Installed Costs	good	fair	poor	poor	fair	good
Portability	poor	poor	poor	poor	good	good
Interference	poor	good	good	good	poor	fair
Privacy	poor	good	good	good	poor	good
Band-Width	poor	fair	good	good	fair	poor

Information for Table 1 was taken from a presentation by Eugene Lubchenko, Philips Laboratories, given at the 1986 IEEE International Conference on Consumer Electronics.

controlling the TV from an easy chair or sofa. Fiber-optic and coaxial cables have good band-width (i.e., information capacity) characteristics.

THE CEBus STANDARDS

When promulgated, the CEBus Standards are intended to ensure that any device marked "CEBus Compatible" can be plugged-in and used in any CEBus System. To accomplish this, the Standards will have to be applicable to all media listed in Table 1, above, and across brand names for a large variety of appliances and accessories. CEBus Systems should, to the degree possible, accept older devices, and anticipate the introduction of new designs. No device can be allowed to "hog" the bus unfairly so that other devices are unable to work. A control in one house must not unintentionally turn on an appliance in a neighbor's house. System security should protect against unauthorized monitoring of activities in homes.

A key question for us is whether the CEBus Standards will take into consideration the special needs of consumers with disabilities. To find an answer, consider what is and what is not being standardized in terms of the four components of home control system which were defined earlier.

Only the last two of the four system components listed above are being standardized in the CEBus Standards. The controller units (actually the logic built into those controller units) and the transmission media are being standardized. The user-interface components and the controlled appliances --- the two components in which the special needs of people with disabilities are addressed --- are not being standardized. That means that the special designs needed by people with disabilities will not be restricted. The designs of user-interface components and controlled appliances will remain market place choices.

Some examples may be helpful. The design of sip and puff switches and of voice recognition devices, two examples of user-interface components, will not be restricted by the CEBus Standards. Neither will the design of electric beds, an example of a controlled appliance, be restricted. However, CEBus Standards could require two-way control signals in CEBus Systems. If two-way control signals are utilized, a transmitting device can expect to receive back from the targeted device a "message understood" signal (the equivalent of the CB's 10-4 message). If no such signal is received back, the transmitting device can be programmed to retransmit its message. This will work if all devices on the CEBus System are able to send and receive messages, and of course to utilize the same codes or languages. The question of two-way signaling has been discussed by the CEBus Committee, but as yet no decision has been made.

So, in theory, CEBus requirements appropriate for the general public also are likely to be appropriate for people with disabilities. However, it would be prudent to be alert for any exceptions to this.

AN INVITATION TO INTERESTED PARTIES

For interested parties unable to participate directly in the development of the Standards, the Electronic Industries Foundation offers to relay news from the CEBus Standards Committee, and to take appropriate suggestions back to the Committee for their consideration. These interested parties may be manufacturers or marketers of products for disabled people, consumers, rehabilitation service providers, or product developers of assistive devices. If you would like to be on the EIF list of interested parties, contact Robert Mills at the address given below.

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THE DEVELOPMENT OF A HEAVY DUTY JOYSTICK

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ABSTRACT

This paper describes the development, construction and application of a heavy duty proportional joystick as well as techniques for its mounting, the reported problems and how these problems have been overcome.

INTRODUCTION

The proportional joystick provides the most responsive and direct control of speed and direction of a powered wheelchair. For those unable to use this method, less direct and slower methods must be used which often mean loss of fine control over the wheelchair. Some individuals have the ability to use a proportional control but, because of their uncontrolled spastic movements and/or environment, damage a standard joystick after a short period of time. A solution to this problem has been found by utilizing a Penny & Giles JCP3 joystick. This joystick has been designed to operate in a military environment, and by adding minimal circuitry, it can be used to provide output signals that emulate a range of standard wheelchair joysticks.

DEVICE DESCRIPTION

The principal design requirements followed for the development of the Heavy Duty Joystick were as follows:

1. strength and durability,
2. a package size easily mounted in accessible and appropriate sights around the wheelchair,
3. the joystick handle should be long enough to act as a grasp by an adult hand as well as the end knob being modifyable to allow for a surer grasp,
4. the joystick must be able to withstand the added forces that a better grasp will inflict upon it,
5. and the device must be able to replace a number of commercial joysticks with differing electrical characteristics and range of movement.

The final Heavy Duty Joystick designed to fit these requirements (see Figure 1) has the joystick and electronics housed in a 3X4X4 inch metal Hammond enclosure, the joystick is mounted through a 3/8" aluminum plate. The mounting holes on this aluminum plate have been arranged so that the joystick orients itself in an "X" configuration or a "T" configuration depending on which plate surface is up. The electronics have been designed to provide the differential voltages needed by both the Everest & Jennings models 3P and 3W, and the single ended outputs of the Invacare Arrow wheelchairs. The joystick shaft and knob are usually customized for each client, with the handle sometimes being shortened from its initial 4" length and the supplied square knob may be replaced with a ball knob or "T" bar attachments of varying size depending on the client's needs. The ON/OFF, HI/LOW switch(es) are also customized for each client to allow for accessibility and/or protection of the switch(es) from the environment and/or client.

DISCUSSION

To date seven Heavy Duty Joysticks have been suppliedfor Everest & Jennings models 3P and 3W, and Invacare Arrow wheelchairs. Factors other than simply over-extension of the joystick, that the Heavy Duty Joystick was designed to over come, have led to eventual joystick breakdown in some joysticks supplied. These factors are:

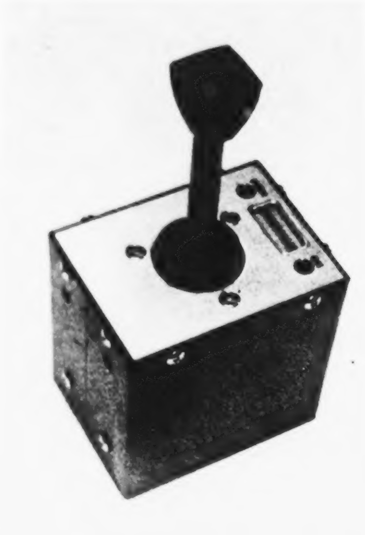

Figure 1: Heavy Duty Proportional Joystick

1) Most of the heavy duty joysticks were supplied with non-rotating "T" bar handles. The non-rotating handles, while providing a essential grasp for the driver, proved to be disastrous to the internal mechanics of the joystick allowing the user to apply a torque to the joystick handle that it was not designed to withstand. This in one case allowed the shaft to be torn from it's epoxy and set screw mounting. In the future all "T" bar prescriptions will be for rotating "T" bars. Those non-rotating "T" bar handles that are in the field have been changed to rotating "T" bars and handles inspected and repairs made as necessary.

2) A re-occurring problem is now showing up with the joystick itself. One particular wire internal to the joystick fatigues from the numerous flexions it undergoes as the joystick is manipulated by the driver. These frequent joystick excursions are also showing visible and electrical signs of wear on the potentiometers. The manufacturer refuses to sell replacement parts for the joystick and insists that each joystick be returned to England for servicing. The costs and time frames for this repair procedure are now being monitored to determine if a more favorable design needs to be developed. Although both problems can be repaired or remedied, without having the joystick sent to England, a permanent solution other than the present repair procedure is needed.

3) The ON/OFF and HI/LOW switch(es) which can be mounted together or separately have been a continuing problem. In most cases compromises are made between a switch size, action and placement that is most suitable to the driver and at the same time a switch and placement that is not easily damaged by the driver and his/her environment.

For optimum use of the Heavy Duty Joystick a rigid mounting of the joystick assembly is required. At the same time the joystick must be located at a position and height that allows for the best control and ease of access by the driver. In some cases this simply means bolting the joystick assembly to the appropriate location on the wheelchair frame. However in most cases the optimum location is a point in space well away from the wheelchair frame and in a position that would interfere with transfers and other daily activities. Commercially available mounting systems designed to swing away when not in use have provennot to be rigid enough and are soon pushed out of reach by the driver through the force applied to the joystick. A Heavy Duty Tray Mount developed by the Mechanical Design and Services Program at the Hugh MacMillan Medical Centre, designed to be an adjustable and swing away tray mount, is now being used as the joystick mount. To date no problems have developed with this system which provides a very sturdy mount that is easily adjusted and swung away.

The initial display on the joystick was simply two light emitting diodes (LED's) for HI/LOW speed and power ON, mounted through the top aluminum plate. In response to needs expressed by clients, a ten segment LED bargragh was added to indicate wheelchair battery charge level. The circuit designed to drive this display monitors the wheelchair's battery voltage and turn off the segments one by one as the voltage decreases. When the voltage lowers to a predetermined critical point, the whole display begins to flash to remind the person that the batteries need to be recharged.

CONCLUSIONS

The Heavy Duty Joystick has gone through several stages of development, as different clients have used it in many different ways and environments. At its current stage it has shown to be an appropriate solution to a long felt need and provides individuals, who would normally use a less direct mobility access method, immediate control over their wheelchair.

ACKNOWLEDGMENT

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SOFTWARE FOR SCREEN DISPLAY OF KEYBOARD FOR NO-HANDS TYPING VIA ULTRASONICALLY SENSED HEAD MOVEMENTS

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ABSTRACT

A computer program was developed that allows quadriplegics and other persons without hand function to enter alphabetic and numeric information and to control computer operations by head movements and activation of a single switch. The hardware consists of an ultrasonic head rotation sensor which replaces the conventional hand-controlled "mouse" cursor on a Macintosh™ personal computer, and a switch that can be adapted to the particular disability. The computer program graphically displays the keyboard on the terminal screen. To type a character, the disabled person rotates his/her head to point the cursor at the desired key display and then activates the switch. The software then transfers the typed letter to the currently active user program. The developed software can be incorporated as part of the operating system's utility programs which can be accessed by any program written for the Macintosh that allows use of the so-called "desktop accessories" and provides for movable windows. This includes programs for word processing, spreadsheets, data bases, music composition and graphics.

INTRODUCTION

Providing access to computers for quadriplegics or other persons without hand function is a significant challenge. There is a great need to provide this avenue to useful work, entertainment, information retrieval and creativity to an estimated 5000 new cases of quadriplegia per year (1). Approaches range from mouthsticks used to peck at the keyboard (2) to elaborate voice-commanded computers with specialized interface hardware and software (3). The mouthstick is the most economical data input device. It has its limitations particularly when more than one key must be depressed simultaneously. It is also not appealing aesthetically - and emphasizes the persons handicap. Much progress has been made toward voice recognition and voice activated commands for control and data input to computers. These systems are ,however, still very limited in terms of the size of recognized vocabulary (a few hundred words or sounds), the training time required to adapt to each new voice, the high sensitivity to environmental noise and the high cost and complexity of these systems. These systems also do not deal well with programs that require cursor or joystick control such as graphics and entertainment type programs.

A commercially available cursor control system (Personics VCS™), that uses ultrasound to detect head movement, gave us the idea that this system could be adapted for quadriplegics without hand function. The ultrasonic cursor control substitutes for the regular "mouse" function in the Macintosh computer. The Macintosh™ computer has a significant advantage for handicapped persons because it is designed to be controlled by cursor movement and activation of a single switch. This minimizes the amount of alphabetic keyboard entry required to control the computer and its programs. This includes such functions as loading and deactivating programs, opening and closing files, printing, and copying files. Graphics, music composition and most entertainment and game programs can also be controlled using the cursor. Thus the combination of the Macintosh™ computer and the ultrasonic cursor control hardware, provides immediate access for quadriplegics to many of the functions of the computer. The only hardware adaptation is to modify the cursor switch so that the quadriplegic can activate it. In most cases this is as simple as attaching the regular mouse switch to the armrest of the wheelchair with velcro straps and gluing a foam rubber riser to the switch. More recently the manufacturer of the ultrasonic head set has developed a version with a mouth-switch that is suitable for people who have no movement below the neck.

The availability of what essentially is an invisible ultrasonic pointer attached to the head, gave us the idea for allowing keyboard entry through software rather than the mechanical keyboard.

This paper describes the features of this software and provides a few examples of uses of the keyboard with unmodified commercial programs for word processing, graphics, and spread sheet.

ULTRASONIC "MOUSE" TYPING

The basic concept that allows typing without physical contact with the computer or keyboard, is to allow the user to move a cursor to a displayed letter on the screen and press a switch. The Macintosh computer operating system has a method of associating position in a certain field with a desired action. By graphically displaying the image of the keyboard on the screen, each key represents a different area in the x, y coordinate field of the cursor. By sensing the location of the cursor, the computer can interpret which character the person typed by a lookup table in the computer's memory.

Hardware

The hardware consists of any model of the Macintosh™ computer (Apple Inc.). The newer versions with 512K or 1 Mbyte of memory and a hard disc are preferable for quadriplegics, who would have difficultly with frequent swapping of floppy discettes. The conventional cursor control or "mouse" is replaced by an ultrasonic head movement sensor (Personics Inc. VCS). The sensor system consists of a ultrasonic transmitter that sits on top of the computer and emits a continuous ultrasonic sound with frequency well above the hearing threshold. A receiver unit, that looks similar to ear phones, is mounted on the operators head. It consists of three microphones. One is on top of the head, the other two are on each side of the head near the ears.

The microphones are connected to an electronic circuit, which detects the phaseshift of the sounds arriving at the three microphones as the head rotates up and down or from side to side. This phase shift is translated into equivalent movements of the mouse in the x and y coordinates of the screen. The conventional Ultrasonic Mouse is supplied with two small switches. One to activate the ultrasound and the other duplicates the switch on the mouse. The ultrasound switch was replaced with a latching switch that needs to be activated only at the start of the session. The other switch was replaced with a phone jack to allow attachment of switches suitable for the particular handicap. The regular mouse switch is wired in parallel, so that it can be used as an alternate to the special switch. A modified head set is also available from Personics Inc. that includes a mouth switch and has the ultrasound permanently activated.

Keyboard Software

The mouse driven keyboard, called KeyMouse, is a desk accessory program for the Macintosh™, written in Pascal. It is compatible with the 128K, 512K and 1Meg Plus machines. It requires no special system, and runs with any program that allows desk accessories (DA).

The KeyMouse DA allows the user to perform all keyboard functions with an screen version of the standard keyboard. The user types a character by moving the cursor to it and activating the switch. The Caps Lock, Shift, Option, and Command keys are programmed to stay on or latch when selected. Programs or menu items that rely on the command key and option key to control special functions will work with the KeyMouse DA. The physical keyboard can be used in conjunction with the KeyMouse DA. The KeyMouse DA can also be used to enter text and numbers into dialog boxes such as used for entry of file names. The only function of the normal keyboard not implemented by KeyMouse DA is getting the keys to repeat.

The keyboard display size is currently fixed at 9x3 cm, which takes up approximately 12% of the display area of the standard Macintosh screen. The keyboard can be moved anywhere within the display area. This is important since the keyboard must remain unobstructed by other windows or dialog boxes during use. Each key on the keyboard is 5x5 mm in size. This area is large enough for precise positioning of the cursor for people with normal vision and head control. Larger displays of the keyboard as well as different alphabets can be programmed, if the need arises, by a simple table change. Figure 1 shows the KeyMouse keyboard and the typical configuration of the computer screen during word processing. Note in this example the latching shift key (darkened key) has been activated, so that the keyboard displays capital letters. The cursor has been placed to type the capital letter "Y".

The KeyMouse DA has several features that make it different from conventional accessory programs on the Macintosh. The first thing that KeyMouse does is to change the system software which allow KeyMouse to remain the back window even though it is being used. This change allows the active application program to remain foremost and occupy the front window of the screen. KeyMouse catches the events of the cursor and switch by becoming active 60 times each second to check for any changes in the cursor status. When such changes signify a new character selected on the screen, the program modifies the system's keyboard event table to make it appear as if the physical key had been pressed. The system then transfers the character to the active applications program as a normal keyboard input. All system changes are removed when either the program or the desk accessory finally finishes.

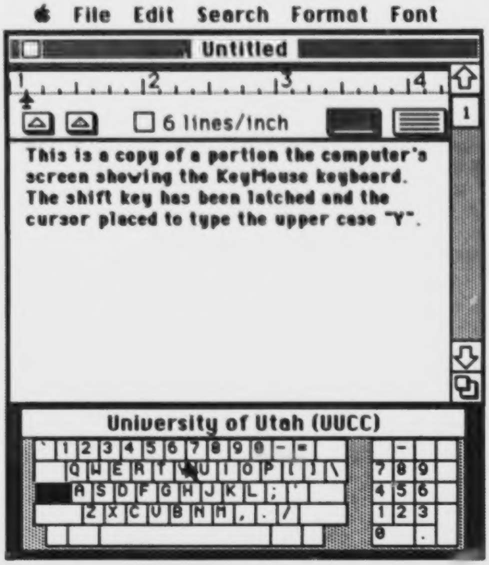
RESULTS - APPLICATION PROGRAMS WORKING WITH KEYMOUSE

KeyMouse DA is expected to work with any program that allows for the functioning of so called desk accessories called from the "apple" menu. It also requires that the application program have movable windows so that room for displaying the keyboard is made available. The programs that have been tried and work with KeyMouse are MacWrite™, MacProject™, Full Paint™, Microsoft Excel™, Powerhouse™ and Cricket Graph.

Programs that do not work with KeyMouse are MacPaint™ and MacDraw™. The reason that MacPaint does not work with KeyMouse is that MacPaint does not allow a variable window size. Hence no space is left for the display of the keyboard that does not overlap the drawing window. This problem is fixed with FullPaint™. This more versatile and powerful version of MacPaint allows for an adjustable size of the drawing window.

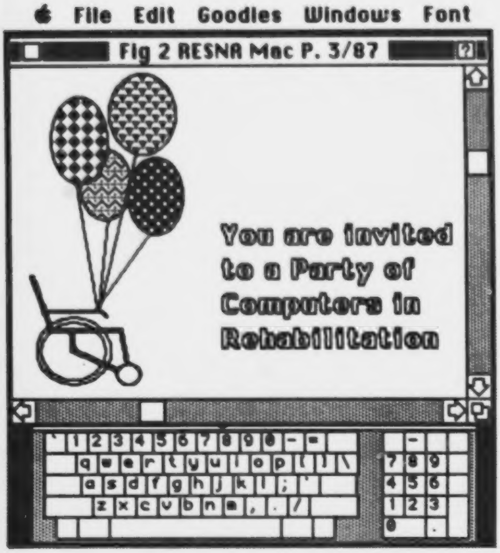
MacDraw™ does not work because, for unknown reasons, it closes all desk accessories and discards them from the screen whenever any of the tools in MacDraw are activated.

Figure 2. shows the screen image of the computer when using the Full Paint™ to design a party invitation. The picture design is made by head movements and switch control. The KeyMouse keyboard is used only for printing the text.



This is a copy of a portion the computer's screen showing the KeyMouse keyboard. The shift key has been latched and the cursor placed to type the upper case "Y".

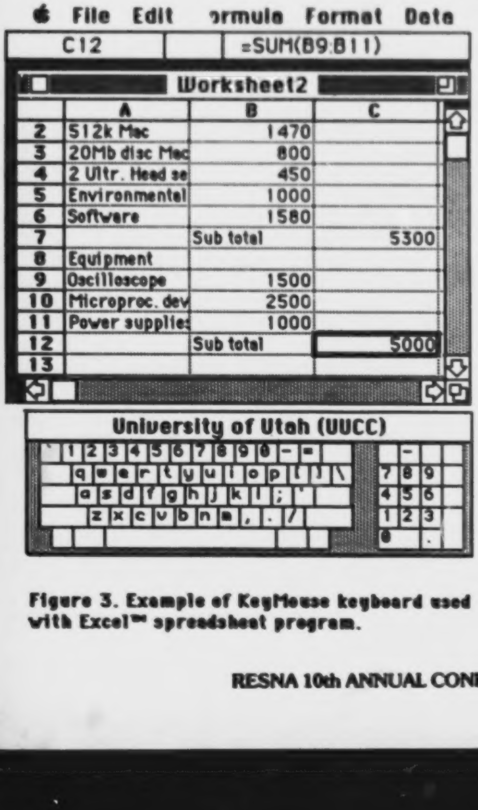
Figure 1. Example of word processing using the KeyMouse keyboard display. The keyboard is in actual size. The cursor is placed to type the letter "Y".



You are invited to a Party of Computers in Rehabilitation

Figure 2. Computer's display screen illustrating design of Party invitation using FullPaint™ and KeyMouse keyboard to enter text.

Figure 3. shows an example of using KeyMouse to enter data into a spreadsheet program (Microsoft Excel™). The combination of cursor control and alphabetic and numeric entry using head movements and activation of a single switch allows a person without hand function to use the versatile management tools of this commercially available software.



C12 =SUM(B9:B11)

	A	B	C
2	512k Mac	1470	
3	20Mb disc Mac	800	
4	2 Ultr. Head se	450	
5	Environmental	1000	
6	Software	1580	
7		Sub total	5300
8	Equipment		
9	Oscilloscope	1500	
10	Microproc. dev	2500	
11	Power supplies	1000	
12		Sub total	5000
13			

Figure 3. Example of KeyMouse keyboard used with Excel™ spreadsheet program.

DISCUSSION

The computer and the software has been available in our Occupational Therapy department for approximately one year. Three fourth of the therapists have become familiar with the system. At present computer training is an optional part of the rehabilitation process at our center. Approximately 40 spinal cord injured patients have had some exposure to the Macintosh™. Of these patients only 4 have been quadriplegics that needed the use of KeyMouse and the ultrasonic head movement sensor. We are in the process of formalizing a study that will include specific training schedules and measurement of the speed of learning and the acceptance of the system by patients.

Most quadriplegics will require assistance in mounting the head movement sensor and switch at the beginning of each session. Thereafter the patient is capable of performing all of the required functions to control the computer's operations unassisted.

The KeyMouse program is available in the public domain and may be copied for personal use without charge. Incorporation of this program into a commercial product or charging for it requires the permission from the University of Utah Computer Center.

ACKNOWLEDGMENT

We gratefully acknowledge the donation of 3 Macintosh™ computers from Apple Inc. in support of this project.

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The Development of a Non-Contact Eyetracking System for Communication and Control

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ABSTRACT

Selection based on visual gaze is a promising mode of input for communication and control. Systems that use remotely mounted cameras to monitor eye position offer many advantages over methods that require the user to wear sensing apparatus. A primary disadvantage of currently available non-contact systems is that they require a stable head position to operate. This paper presents a method of implementing non-contact eyetracking that poses little constraints on user head position. The system uses the corneal reflection-pupil center method in conjunction to with a mirror tracking system to maintain the camera's view on the eye.

INTRODUCTION

The use of visual gaze as a user interface to rehabilitative devices offers many advantages over other currently used modes of input. The most important of these is a potential for unprecedented input rates when compared to interfaces such as single switch based scanning. In addition, eye control offers a user an extremely natural way to interact with a technological aid. Although electronic eye gaze measurement systems have been used for many years in other settings (e.g., psychological research), they have only seen commercial realization in rehabilitation for a short time [1,2].

A companion paper has presented some of the design criteria that has made the implementation of ocular control suystems difficult [3]. They are:

Real time operation The system must be capable of measuring eye position in real time.

User comfort The user of an eye gaze communication system will in theory be using it for most of his/her waking hours. The system should not pose any discomfort and should be as unobtrusive as possible.

Moderate cost Because this application is for an individual user, the system cost must be moderate.

Relative portability Although the ideal device would battery operated and small, this is not possible with some of the technologies currently being investigated. The system should be relatively portable, roughly the size a desktop unit.

Accuracy The efficiency of an eye gaze system is primarily determined by the measurement accuracy. While a system that can measure two different gaze positions could be used with a coding strategy, it is desirable to have enough targets to allow direct selection.

THE NON-CONTACT APPROACH

Many techniques have been developed to measure the direction of a person's gaze. One promising technique for rehabilitation applications is the corneal reflection-pupil center method. One of its greatest benefits is that it is a non-contact technique; the user is not required to wear any sensing apparatus. This feature makes the approach much more desirable in some respects than other approaches [3,4]. Both of the commercially available ocular control systems use this technique [1,2]. These systems however have one major limitaion; they restrict head movement. In corneal reflection-pupil center based systems it is necessary to image a small area of the face (typically 1 inch square), in order to achieve reasonable measurement resolution. This often imposes severe constraints on the user's allowable head movement. If an individual's disability prevents him/her from maintaining relatively constant head position, the system may be unreliable or even inoperable.

This paper presents a system design that attempts to overcome the limitations inherent in previous designs. It uses a technique previously presented by Merchant et., al., [5] that incorporates two computer controlled rotating mirrors into the optical path of the system. These mirrors redirect the optical path of the camera and allow a much larger range of vision without effective loss of resolution. In operation, these mirrors move as the user's head moves to maintain a constant view of the user's eye.

THEORETICAL CONSIDERATIONS

The corneal reflection-pupil center technique depends on the fact that the relative distance between the center of the pupil and the center of the corneal reflection (CR) changes with respect to eye movement. Figure 1. shows a view of the eye looking straight ahead. When the eye looks to the side, both the pupil and CR are displaced (Figure 2.). If the head were fixed with respect to the display, either feature would provide a measurement of gaze. In practice, even slight movements of the head will occur (without the use of a bite plate) resulting in large measurement errors (.005 inch of head movement corresponds to 1 degree of eye rotation). By measuring both pupil and CR movements, head movement has no effect. This allows a camera to be remotely mounted with no contact to the user.

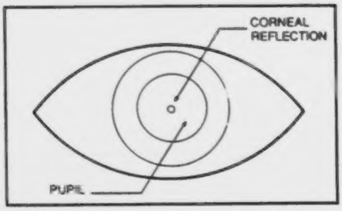

Figure 1. The eye looking straight ahead

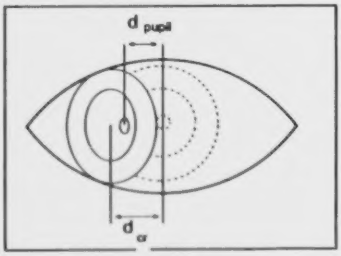

Figure 2. The results of eye rotation

The basic geometry of the eye results in the relative movement of the CR with respect to the pupil. The CR is a virtual image of a light source that occurs because the cornea acts as a spherical mirror. The movement of the CR for angular rotation of the eye is:

$$d_{cr} = a \sin \Theta$$

where:
a = distance from the center of the eye to the center of curvature of the cornea
Θ = angular rotation of the eye

The movement of the pupil for angular rotation of the eye is:

$$d_{pupil} = b \sin \Theta$$

where: b = distance from the center of the eye to the center of the pupil

The relative movement of the CR with respect to the pupil is:

$$d_{gaze} = k \sin \Theta$$

where: $k = a - b$

To determine visual gaze with this method it is necessary to first perform a calibration that presents several stimulus points to the user and records measured d_{gaze}. A mapping function such as a Bezier interpolation can then be applied during real time operation to evaluate where the user is looking based oncorneal reflection data.

Although calibration techniques eliminate the need to determine the anatomical distances a and b, typical values for these dimensions can be used to determine expected maximum values for system resolution. This determination will be presented along one axis for a typical system configuration.

For a user who is viewing a monitor which has a horizontal dimension x and is positioned a distance z from the eye, a maximum rotational displacement for the eye is:

$$\Theta_{max} = 2 \tan^{-1} \frac{x}{2z}$$

The maximum change in distance between the corneal reflection and the pupil that will be measured over this viewing range is:

$$d_{max} = 2k \sin \frac{\Theta_{max}}{2}$$

For a given optical configuration and and a given camera/digitizer resolution it is possible to determine the maximum target resolution based on d_{max}:

$$n_{max} = d_{max} \frac{q}{v}$$

where:
q = camera/digitizer resolution
v = viewing dimension of the camera
The resulting equation is

$$n_{max} = \frac{2(a-b) \sin \frac{2 \tan^{-1} \frac{x}{2z}}{2} q}{v}$$

For average anatomical values and a typical system configuration of a 12 inch diagonal monitor, a 18 inch viewing distance, a 2 inch camera viewing range and a camera resolution of 256 the maximum target resolution is:

$$n_{max} = 10$$

This figure represents a theoretical limit and in actual practice it should be reduced by a factor of 2 to 3. It becomes appararent that the addition of a mirror tracking system that would allow a smaller camera viewing range would also potentially acheive a more acceptable n_{max}.

IMPLEMENTATION

Figure 3. shows a block diagram of the current implementation. It is essentially a scaled down personal computer based version of the system orriginally described by Merchant, et., al. [5] The controlling computer is an IBM AT with a parallel digital interface and a digital to analog converter.

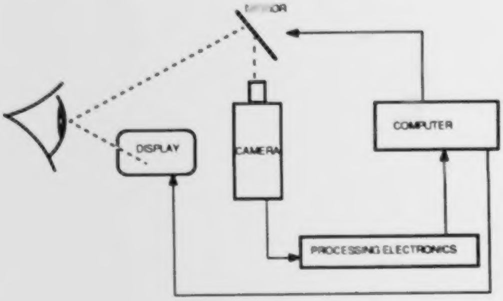

Figure 3. Block diagram of system implementation

Corneal Reflection-Pupil Center Tracker

The parallel interface of the AT is connected to an ISCAN RK-426 corneal reflection-pupil center tracker. The ISCAN accepts input from an infra-red video camera and outputs the position of the CR and pupil center at 30 hz. The RK-426 provides 9 bits of data in the horizontal direction and 8 bits in the vertical. This commercial system, manufactured by ISCAN Inc. of Cambridge, Mass., was chosen for the prototype for its performance as well as the reduced development time inherent in using off-the-shelf technology.
The viewing area of the camera has been set at 1 inch thus allowing the maximum target resolution using a 12 inch monitor to be 40 locations in the horizontal and 20 in the vertical.

Mirror Tracker

In order to increase the effective viewing area of the camera, a pair of 1 inch square, orthogonally mounted General Scanning mirror trackers have been mounted in the optical pathway. The mirrors are attached to precision motors and are capable of being rotated in increments in the range of 1 minute of arc.

Controlling Software

The software is written in C and consists of three major components. The data module reads the ISCAN for pupil CR data and performs some error rejection. The tracking module monitors the CR and pupil position and drives the motors of the two mirrors so as to keep the pupil centered in the video image. The communication module performs calibration and real time control functions.

System Performance

The performance of the prototype system allows the user approximately 12 x 12 inch movement in the plane of the viewing area, and 2-3 inches along the optical axis. The latter is a function of the depth of field of the camera. This value is expected to be increased with the addition of an auto-focus camera.

Within this movement volume the accuracy of the ISCAN RK-426 has been determined to be unchanged from its originally measured values. The position of the mirrors must be initialized by means of a joystick, and the system will adequately track slow head movements. Improvements are being made to increase the speed of calculation to allow the system to follow movements that would be made by a wide range of disabled users.

CONCLUSION

The current work is focused on further system refinement. Increased error rejection and recovery functions are needed as well as a method for compensating for head movement in the z direction e.g., computer controlled focusing). The final stage of this project will incorporate automatic search procedures for initializing the location of the eye and recovery if the image is lost.

With the completion of this final stage of system development, the project will turn its attention to the human factors concerns of communication rate, and keyboard layout. With regard to the latter, the project will examine the decrease in resolution made possible by using a smaller number of targets to represent the alphabet. Foulds et al [7] present a method of using only 11 keys to achieve key selection efficiencies (1.11 keystrokes per character) comparable to 27 keys (1.0 ketstrokes per character. This possible reduction in resolution will potentially contribute to increasing the utility and reducing the cost of the non-contact eye-tracking system.

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A 'SMART' MICROPROCESSOR-BASED INFRA-RED DATA LINK TO ENABLE WIRELESS WHEELCHAIR-TO-'LANDBASE' COMMUNICATION WITH PERSONAL COMPUTER AND ENVIRONMENTAL CONTROL DEVICES

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ABSTRACT

Full independence for those in wheelchairs includes the freedom to interact at will with devices found in the home and office. At present many wheelchair-based people need to be "plugged" in to desk-top personal computers in order to take full advantage of their onboard lap-top devices or communication boards.

The data link that we have developed uses the latest INFRA-RED technology and is based on two 8085 fully programmable microprocessors which interact with each other in full duplex RS232C format. The link can operate either as a simple relayer of serial data or can be programmed to act as a customised front-end, to match the user's chosen input (keyboard, blow-suck, joystick) and output controller (environmental control, alarm, computer input etc.).

We believe that the flexibility of a modular choice of input, serial link, and output will give a new degree of freedom to severely incapacitated individuals.

INTRODUCTION

Modern technology is, perhaps for the first time making it possible for profoundly locomotor and/or speech-disabled people to communicate with others and to manipulate their world through environmental control systems and other "intelligent" peripherals.

A valuable spin-off has been the freeing of care-givers from repetitive, arduous or/and boring tasks, most of which can now be done by disabled people themselves, thus allowing the "human use of human beings", (Wiener, 1950). Apart from the obvious advantages, this has profound psychological benefits in that a great deal of functional independence can be achieved even for severely disabled individuals, changing their perceptions of themselves for the better.

A serious deficiency of present wheelchair or other mobile based systems eg. lap-top computers, selector boards, is that there is no easy communication possible with other fixed (land-based) technologies without the assistance of another individual to make the physical connection - usually by cable and plug.

We have attempted in this prototype system to address this problem and to produce as modular and therefore as adaptable a solution as possible, given the wide range of impairments on the one hand, and an even wider choice of addressible devices on the other.

DESIGN

The prototype design was based on the needs of a high C3 quadruplegic, Graeme Clarke, who has no speech, only limited neck control and very poor breath control. However, in our ergonomic assessment of the problem we were careful not to limit any possible later options for other disabilities.

A modular design was adopted with the following components:

1. A pair of full-duplex INFRA-RED (I-R) devices making up a bidirectional RS232C compatible data link.
2. A wheelchair based ("ROVING") single board ("COMMAND") micro-computer (Computer-Thing, EVA 1985) with local memory (8K), A-D conversion (2 channels) customisable by software to the particular I-O needs of the disabled users.
3. A land-based identical micro-computer ("EXECUTOR") with similar powers except that it can act both as a local data switching device between the user and a personal computer (PC) and/or a stand-alone simple environmental control system.

In the particular case of Graeme Clarke who drives his wheelchair by a chin-joystick and a single, chin-operated ON/OFF switch, we configured the system illustrated in Figure 1.

At present we have 7 possible control modes for the roving (COMMAND) micro. These are serially selected by depressions of the chin switch which has a toggle-type action (we call this the fire-button). After the seventh mode the selector reverts to the first:

1. Standby is a low-power consumption mode which leaves the communication-channel "on" but turns all other wheelchair-based systems off.
2. In wheelchair-drive mode the joystick behaves as a normal driving control lever.
3. The land-based PC is a BBC-B Microcomputer and in this mode the chair's joystick operates as a surrogate (analog) of the games joystick input.

4. Though not yet fully implemented since we do not as yet have a suitable lap-computer, the chair's joystick behaves as the cursor-controller/selector of the local device.
5. The emergency/alarm call activates an on-board buzzer and is fail-safe elicited by any movement of the joystick while in this mode.

6,7 etc. Above states relate mainly to local/on-board wheelchair based functions. For future use, 9 additional modes are available for device drivers addressing inter alia a commercial environmental control system. Naturally the local software in the command micro will need to reflect the needs of the particular device(s) addressed on the land-based end. However, it is very simple by means of a look-up table to send up to 4 specific ASCII words/bit patterns across the RS232 link depending on the chosen NORTH/SOUTH/EAST/WEST movement of the joystick, once in an appropriately selected mode.

Besides the RS232C port for serial I-R communication a second serial port is available at either end for another "intelligent" device, since many new consumer products are now controllable as computer peripherals. In addition, the land-based executive unit has two channels of D-A conversion to mirror the on-board joystick movements by two analog voltages. Also on the executive device are 6 channels of thyristor controlled solid state (mains switching) relays with a dimming function which can be disabled by software. This is a simple environmental controller which does not any additional hardware.

At present, status/mode selection is displayed by a row of LEDS on the wheelchair console, but later this will be optionally expanded to a 4 or 8 line liquid crystal alphanumeric display. This will be particularly useful to double as a "remote screen" while addressing the land-based P-C from some distance away.

Though the range of the data link is at present limited to 8 meters, there is no reason why, with the use of greater luminant power or extra transponding I-R devices, all functions should not be controllable anywhere in the house of the user.

RESULTS AND DISCUSSION

At present only 2 systems are up and running. One is being used for field-evaluation by Graeme Clarke while the second identical system is used as a laboratory emulator for software development.

Printed circuit technology has made the size/weight and power consumption appropriate for attachment to an electric wheelchair. Software is currently developed on a PC-based Microcomputer Development System and cross-assembled for the 8085. Since we are constantly changing the design, software is at present on RAM but we envisage that final realization will be individually tailored for the particular user and programmed into EPROM.

It is believed that the ultimate cost of the system minus specialised inputs and or outputs eg. speech, will be less than $US 1000.

ACKNOWLEDGEMENTS

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ADDRESS

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For Fig.I. see following page.

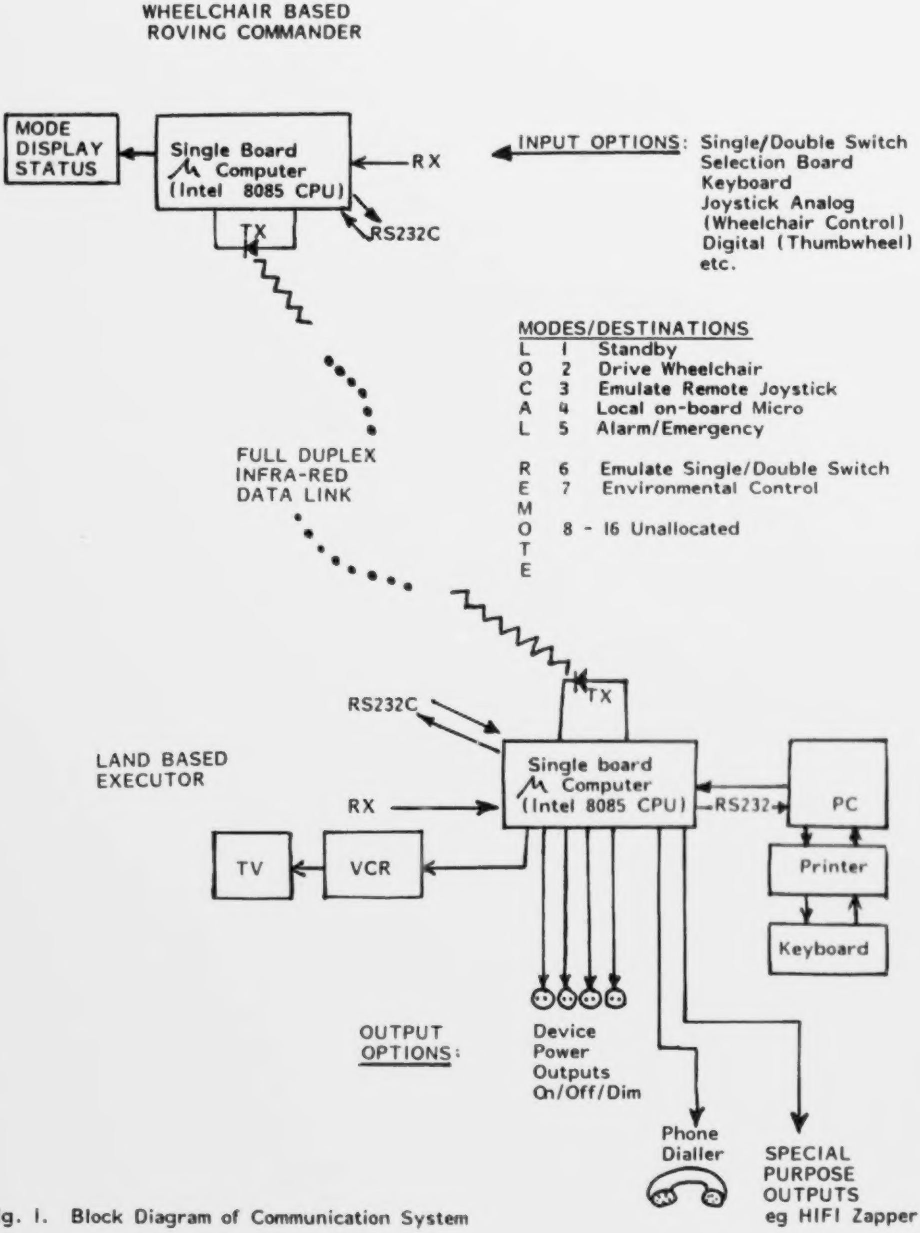
WHEELCHAIR BASED
ROVING COMMANDER
MODE
DISPLAY
STATUS
Single Board
M Computer
(Intel 8085 CPU)
RX
TX
RS232C
INPUT OPTIONS: Single/Double Switch
Selection Board
Keyboard
Joystick Analog
(Wheelchair Control)
Digital (Thumbwheel)
etc.
MODES/DESTINATIONS
LOCAL
1 Standby
2 Drive Wheelchair
3 Emulate Remote Joystick
4 Local on-board Micro
5 Alarm/Emergency
REMOTE
6 Emulate Single/Double Switch
7 Environmental Control
8 - 16 Unallocated
FULL DUPLEX
INFRA-RED
DATA LINK
TX
RS232C
LAND BASED
EXECUTOR
Single board
M Computer
(Intel 8085 CPU)
RX
RS232
PC
Printer
Keyboard
TV
VCR
OUTPUT
OPTIONS:
Device
Power
Outputs
On/Off/Dim
Phone
Dialler
SPECIAL
PURPOSE
OUTPUTS
eg HIFI Zapper

Fig. 1. Block Diagram of Communication System

CAD-Clad
Computer-Aided Clothing Design for People with Special Needs

Karen J. Holloway
Rehabilitation R&D Center
Veterans Administration Medical Center

ABSTRACT

CAD-Clad is a new project at the VA Rehabilitation Research and Development Center that seeks to investigate the use of Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) technology to address the unique clothing and dressing needs of people with disabilities. The intent is to: prove that CAD technology can be used to design well-fitting clothing that is appropriate to the needs of people with disabilities; provide the foundation for further research into innovative clothing concepts; and, investigate effective, non-disruptive measuring techniques for people who cannot sit or stand for long periods of time without support.

This paper will discuss the state of the art in garment design, patternmaking and manufacturing processes, currently available clothing for the disabled, and existing, relevant CAD applications in various industries (i.e., in the manufacture of lower limb prostheses). Work to date and plans for the future will be presented in tandem with strategies for dissemination of this technology and a discussion of potential applications for the research.

INTRODUCTION

Clothing is not only a factor in how a person looks but also in how a person feels. It is a statement of self but it is also a barrier that each of us encounters every day. Clothing is essentially a portable environment (1) within which we live almost every moment of our lives.

Disabled individuals, like everyone else, seek the greatest degree of autonomy possible in performing activities of daily living. Disabled individuals also want to be as stylish as their peers. In this light, well-designed clothing, that takes advantage of the capabilities of a person, and meets his or her physical needs, can be considered a rehabilitative tool and an aid to independence. Clothing designed with 'do-able' fasteners, sufficient ease to facilitate dressing, with consideration to cost, fit comfort and style, and with accomodations for other devices that may be in use (such as braces or a wheelchair) can contribute significantly to the quality of life of individuals.

Currently the clothing needs of people with physical disabilities and limitations are not adequately addressed by mainstream designers and manufacturers. Cottage Industry and small scale operations do exist, but much of their work is done on a one-to-one custom fit basis. Specially made garments may consider physical needs, but they are often minimally styled, out of step with current fashion, or designed to meet the physical requirements of the *average* wheelchair user, or the *average* person with arthritis. In the case of custom design, the results are one time, individual solutions that are often expensive and not always available to the majority of people with disabilities. In contrast, ready-to-wear garments may fill some, but not all, of the physical needs of the individual while ignoring the positive psychosocial and rehabilitative aspects of clothing. Altering ready-to-wear garments is another option but it too can be expensive, especially if mistakes are made.

BACKGROUND

This project grew out of: 1) a demonstrated need for accessible daywear for people in long term care facilities; and, 2) wishful thinking on the part of the principal investigator for a computer system that would enable one to enter basic body measurements, select clothing features, press a button, and receive a custom designed pattern (see Figure 1). In 1984, this investigator was part of team researching a Veterans Administration Skilled Nursing Facility for potential applications of an interactive clinical robotic aid (3). During observation, it became clear that most of the residents spent their day in pajamas or sweat suits. While it is not certain if this was the preference of the residents or the staff, it is evident that features common to everyday clothing (e.g., complex fasteners such as zippers and buttons, and less design ease than pajamas or sweats) pose problems to those who dress themselves as well as those who assist others in dressing.

State of the art in specialized clothing

In recent years, with heightened interest in specialized clothing for sports activities, industrial use and energy conservation, clothing design for special purposes has become an important field (1). This change in focus has been demonstrated by the increased availability of clothing for people with physical limitations and physical needs different from the rest of the population (i.e., nursing mothers). Typically, small manufacturing firms either produce a line of garments for a specific population in a preestablished size range, or hand draft patterns and custom-make garments based on a person's measurements and a limited selection of styles. Two notable

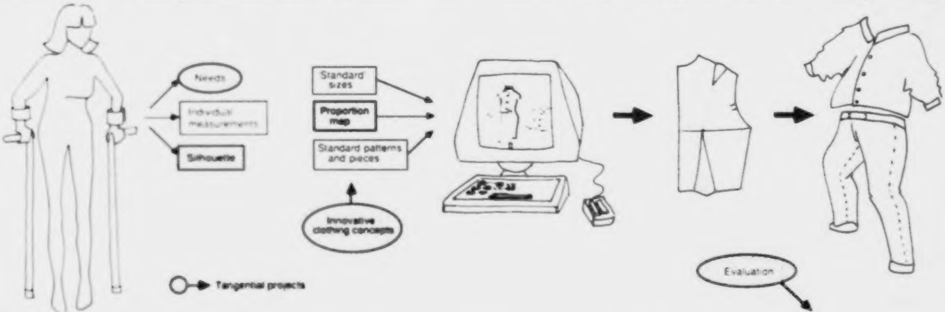

Figure 1: Graphic representation of the proposed system. Heavy lines indicate potential areas of research and development.

manufacturers are Techni-Flair and Individuality, Inc.

1) Techni-Flair is a small company that sells a line of casual clothing with 'for your eyes only' features, like strategically located zippers, by mail order and through chapters of the Paralyzed Veterans of America. The company has done some innovative work with pants for wheelchair users while keeping prices low (approximately $35 for a pair of pants). Unfortunately, fit can still be a problem because standard sizes are a necessity at this level of operation. In comparison, 2) Individuality Inc. makes clothing according to individual measurements and from a limited style selection. Garments are destined to fit, but they are very costly ($140 for a pair of gabardine trousers with dresses costing up to $210) because each garment has to be drafted by hand. Their innovation has been to specify the measurements that are necessary for a good fit and to demonstrate, to the consumer, how the measurements are to be taken.

Relevant computer applications

Relevant computer applications include the following.

1) Clothing Design Concepts, a microcomputer-based system that produces basic pant, skirt, sleeve and bodice blocks for individuals (4). (Block patterns are basic patterns from which all designs are developed.) Unfortunately, this system cannot accommodate asymetry or similarly unique body shapes.
2) Synthesis (Transformer CAD, Inc.), a program that allows a designer to change a master drawing by virtue of information stored in a spread sheet. Currently the parent company is investigating the use of this software in the clothing industry.
3) The systems used by Hood Sailmakers and Nike Athletic Footwear to design and manufacture their products.
4) The Computer-Aided Socket Design system developed to emulate the function of a prosthetist fitting a below-knee amputee with a prosthetic socket (5).

The sum of these applications provides a strong foundation on which to demonstrate the feasibility of computer-aided clothing design for people with special needs.

The Computer-Aided Socket Design (CASD) system is the most significant to this project as it quantifies the skills and methods employed by artisan prosthetists and proves that custom design of rehabilitative devices can be achieved using CAD technology. The CASD system allows the operator to make changes to a primitive socket database according to clinical measurements. From the modified database, using a computer numerically controlled milling machine, a positive mold is made over which the prosthetic socket is formed.A notable feature of the CASD system is the shape management package that permits easy data storage, retrieval and transmission and, subsequently, assures amputees of progressively better fitting prostheses. Other benefits include uniform socket quality and a detailed description of the methods required to produce a good fit.

State of the art in the textile and apparel industries

Computers are relatively new to the textile and apparel industries, especially in terms of garment design and manufacture. The most prevalent applications are in inventory control and production management, laser cutting of fabric, and the sizing and grading of markers (the paper patterns that are used when cutting fabric by hand). Two dimensional CAD, noted for its ability to update old designs quickly, has proven itself a viable technology for pattern development and modification.

Unfortunately, economics plays a dominant role in the availability of fashionable, suitable clothing for people with disabilities. With the present state of the art in fashion industry technology, it is simply not profitable to produce such clothing in the relatively small quantities required (a 'small' manufacturing run in the garment industry is defined as 10,000 units). Every physical limitation, or combination of limitations, requires an individual solution to tailoring and fit. In addition, disabilities vary in their cause, their stage of development, and their effect on the individual's facility with dressing and performing other basic functions (2). Evidence suggests that custom designed garments are the ideal, but it will take a general solution to make them feasible.

WORK TO DATE

Work to date includes an extensive literature and product search to investigate the prevailing design, patternmaking, and manufacturing processes in the textile and apparel industries, existing computer applications in the fashion industry, and currently available clothing and rehabilitative devices for the disabled. In the year since research began, contacts have been made with software and apparel manufacturers, people with disabilities, researchers concerned with the clothing needs of the disabled, occupational and physical therapists, and other health care professionals, and system specifications drawn up relative to each group's concerns.

In Autumn 1986, the principal investigator, Karen Holloway, was instructed in flat patterndrafting techniques and is now able to draft a custom pattern, create a pattern from an existing garment, and create a pattern from a garment sketch. Ms. Holloway also coordinated a student design project at Stanford University to develop innovative fasteners for people with hand and arm limitations. The students were required to design a fastener that would enable an individual with decreased manipulation capabilities and limited range of motion in the upper torso to dress independently. (Future efforts in the development of clothing for people with special needs will require the redefinition of the state of the art in garment closure and the development of new fastener technology.)

During this period, Erik Valainis, the development team's computer specialist, evaluated several micro and mainframe computer systems for use in this project. (Preliminary findings indicate that the IBM-PC/AT will be a good low-end development system, and one that many small manufacturers can ultimately afford.) And, Jeff Aldrich, the team's computer graphic and human factors specialist, developed a 3D wireframe human model. Among it's features are link-end pivot points that permit rotation in user-defined planes and ranges of motion. More importantly, any portion of the 3D model can be scaled independently, and about different axes, to create a variety of body types.

METHODS AND MATERIALS

This project seeks to provide a general solution to the individual fitting, dressing and functional clothing requirements of people with special needs. The *specific* goals of the project are:

1) to collect sufficient human factors and anthropometric information (such as height, weight, body girths and lengths) to set up a simple database;
2) to create a link between that database and the CAD environment; and,
3) to test this system by producing patterns and clothing samples for several different sets of specific anthropometric data (see Figure1).

Technical development will be emphasized. Efforts will be focused on overall system development, and the generation of accurate digital and graphic representations of the human body for use in garment construction and manufacture.

More specifically, basic flat patterns and 2 and 3D images will be created from standards currently used by the home sewing industry (6) and anthropometric guidelines set forth in *Humanscale 1/2/3* (7). It is expected that these standards will facilitate the creation of custom flat patterns and computer graphic images that reflect the silhouette of a given individual. Basic measurements (e.g., chest, waist and hips) will be taken initially to chose a standard, or features of several standards, which match the body size and type of the individual most closely. The system will be programmed to analyze the measurements and designate the appropriate basic pattern. Additional measurements will be taken, as needed, to create an accurate composite graphic image.

Anthropometric information will be gathered as part of a nine month study to examine different methods for taking human body measurements, and to determine which of several methods will yield the most accurate and reproducible results across body types. It will also be important to determine the quantity, as well as the quality, of measurements that are necessary to produce a custom fit. Measurements will be taken in one or more of the following manners: with a tape measure; with a three-dimensional digitizer; or, by fitting the individual with a muslin garment from which pertinent measurements will be derived.

Once sufficient data is acquired, a flat pattern will be drafted and a muslin test garment constructed. (In traditional flat pattern design, all block patterns are tested in muslin for accuracy, seamline balance and fit. Alterations are made to the muslin and corresponding corrections are transferred to the block.) Quantification of this process is expected to contribute significantly to the definition of parameters for a knowledge-based system for computer-aided clothing design.

SIGNIFICANCE

Those who will directly benefit from this technology include people with disabilities that are characterized by functional limitations in the hand and arm categories, limited overall body strength and limited range of motion. This technology can also be applied to anyone with a unique body shape or a particular fitting problem (such as those caused by physiological changes due to aging, curvature of the spine, amputation or the use of a wheelchair). This technology is especially significant given the forecasted increase in the elderly population and the accompanying changes in health services that will be required. In 1980 there were 27 million people over 65 living in the US. That number is expected to rise by 12.3 million to 39.3 million, or 14% of the total US population, by the year 2010 (8).

These predictions are of major concern because the prevalence of chronic illness will rise in proportion to the number of people in the elderly category. Consequently, a larger percentage of the population in the future will either require full-time, skilled nursing care in institutions or some other form of long-term care. Application of existing CAD/CAM technology to the development of clothing that compensates for functional limitations, and encourages people to dress themselves, could lessen the burden of caregiving and reduce the need for institutional care.

FUTURE PLANS

The development potential of this project is great. Once the technology is proven, custom patterns could be available through the mail, specified and printed out in fabric stores, or prescribed by clinicians and therapists through health service organization. (This will necessitate the design and development of a human/machine interface appropriate to the needs of widely different user groups.) Clothing to meet the needs of certain populations (such as those in skilled nursing facilities) might become more viable, as well. A protocol for acquiring anthropometric data on people with disabilities will be required in addition to development of a comprehensive statistical database and research into innovative clothing design concepts and fastener technology. An acceptable range of cost of the system, service and product should be specified and efforts made to stay within that range.

Design and construction of knowledge-based software (the 'expert' system approach), through the quantification of clothing design, patterndrafting, and fitting techniques, may contribute to the reduction of the design/production cycle. A high-end central database may be the ultimate solution. Independent contractors, manufacturers and service delivery organizations would access the system via modem. The most advanced technology would then be available on a time-share basis, and affordable to many instead of few.

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Evaluation of Accessability by the Physically Disabled Student to the Icon Computer

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Clinical Session

ABSTRACT

During 1985 - 1986 a multidisciplinary team of professionals with technical and clinical expertise worked to fulfill a contract with the Ontario Ministry of Education to provide physically disabled students access to the Icon microcomputer, the first of the Ontario Grant elegible microcomputer systems (G.E.M.S.). The clinical evaluations of both students and computer, and the technical development of an interface unit will be presented. The integration of clinical and technical expertise provided challenges and learning opportunities as team members examined goals, needs, possible outcomes and implications of various design strategies.

INTRODUCTION

With the advent of Bill 82 in Ontario, many more disabled students are being integrated into neighbourhood schools. Computers as an aid to instruction are becoming a valuable adjunct to classroom teaching. The advantages of word processing for anyone with impaired writing ability (legibility, speed, organization) are well known. Ontario's Ministry of Education had established computers and curriculum integrated software programs as a priority in 1981; the ICON computer entered the marked as the first Ontario grant eligible educational microcomputer system, meeting a wide range of standards and allowing schools to receive grants toward their purchase. At the same time, people working in Rehabilitation settings were aware of a wide range of computer adaptations commercially available to allow disabled clients access to computers. In early 1985 a team of electronics engineers/technicians, programmers, occupational therapists, teachers, and a psychologist from HMMC were awarded a contract by the Ontario Ministry of Education to assess the needs of disabled students with regard to use of the ICON, to develop a method of interfacing adapted keyboards to the ICON, and to write a software program to explain the appropriate application and use of such equipment to school personnel.

BACKGROUND

The ICON computer was developed in Ontario to the specifications of the Ontario Ministry of Education. It is a network system allowing up to 32 stations of 512K each to be served by a 10 or 70 megabyte hard disc lexicon and a single printer. The ICON computer has a closed architecture. The keyboard (standard QWERTY with additional numeric keypad on the right side) and monitor with a rotating tilting base are all assembled in one casing. A trackball is positioned to the upper right of the keyboard; it operates the cursor and its use is an integral part of all software. The ICON weighs about 50 lb. It has a built-in word processor, drawing and logo programs which use icons extensively to select controls/instructions. A work environment called "ambience" allows teacher and student task spaces, either private or shared with the general classroom, as well as access to the Ont. Ministry of Education curriculum software programs, and to the resident languages (C, Pascal, Logo and Basic).

METHODS

Stage 1 of the project included both technical and clinical evaluations of the ICON. Clinically 29 children, aged 5-19 years, with a wide range of disabilities and seating positions were assessed with relation to difficulties using the ICON computer "as-is".

Keyguards, removal of the trackball into an external casing with an extended cable, adjustable tables and removal of the monitor from the base were suggested solutions, along with the more involved solutions of adapted keyboards connected through the interface unit.[1]

Interfaces that were deemed useful by clinical personnel were identified; they included serial and parallel port remote keyboards, miniature and expanded keyboards, joystick and single switch access via a "mod" keyboard[2,3]. All these adaptations had different inputs that needed to be accommodated by the interface unit. A prototype interface unit was developed including a remote (infrared) link for these interfaces.

Stage 2 involved testing the interface unit and adaptations within our home centre; stage 3 was a field testing stage outside the centre. As problems in the use of the interface unit were identified, modifications and additions were made. These included increasing the size of a keyboard selection switch, adding an optional autorepeat function to optimize trackball emulation by direction keys, and adding a programmable hold time which allowed consideration of the student's switch activation time.

Concurrently instructional software, the "teacher utility", was written to accompany the interface unit. The program has four sections:

1. An overview of all functions available, including the glossary, help.

2. Instructions on how to hook up the interface unit.

3. A guide to identifying appropriate modifications with reference to the student's physical problem.

4. How to redefine a keyboard layout and to replace the trackball function by cursor key movement.

Field testing identified various problems:

1. A need for teachers to be more aware of how to use computers and software and to feel more at ease with them; a need for technical and moral support for teachers using computerized devices.

2. A tendency to oversubscribe to complicated technical solutions rather than consider appropriate seating and table levels first.

3. Software design: a need to decrease technical terminology and to use lay language; a need for trackball replacement or emulation; a need for an autorepeat key if trackball emulation was used

4. Need for more information on where to purchase and how to fund adaptive equipment.

5. Concern by clinicians as to who would decide on adapted equipment vs. a need for a wider knowledge of available adapted equipment by school personnel.

6. Technical problems such as loosening cables, loose bolts

Some overall problems were distance to field test sites for servicing systems and evaluating students, lack of appropriate software due to the relative newness of the computer system, differences in hardware and software of the installed Icons, as the Icon was still in a developmental stage and was being revised continually.

CONCLUSION

Over the course of the project the challenge of translating technical and clinical terms into lay language to reach the widest audience was a major one. Software was changed often to simplify terminology, make commands clearer, and screen presentation more concise. The interface unit underwent some basic changes to become more reliable and easy to use. The Icon team feels strongly that follow-up in the areas of in-service and written presentations on the appropriate use of computer adaptations is needed. There are over 20,000 Icons presently in use in Ontario schools. As members of the rehabilitation community, we are pleased that the accessing problems of disabled students using the Icon computer are being addressed.

ACKNOWLEDGEMENT:

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THE MOD KEYBOARD: A PROGRESS REPORT

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ABSTRACT

The MOD Keyboard has proven itself to be an effective, inexpensive keyboard replacement device. This paper describes some of the recent developments and improvements of the MOD System.

INTRODUCTION

For many handicapped individuals, the keyboards of today´s computers are either difficult or impossible to use. To alleviate this problem, a number of different devices have been developed. Several of these devices use the keyboard emulation approach. Keyboard emulation involves replacing the physical keyboard with a device that provides the user with an appropriate control interface and electronically emulates the operation of the keyboard it replaces. This approach ensures that the disabled person has access to all commercial software for that computer system. Our solution for the keyboard emulation problem has evolved into the MOD System.

BACKGROUND

The MOD Keyboard consists of a second, inexpensive computer (the Commodore VIC-20) that provides the user with a "keyboard-on-a-screen" (see diagram of Figure 1) (1). A user can choose characters, words or phrases from the screen, using a variety of selection techniques and the MOD Keyboard will send these selections to the target computer. The MOD System offers three main features:

1) Input flexibility. A number of different user interfaces and selection strategies are available.

2) Output flexibility. The MOD Keyboard can emulate keyboard operation for the Apple II+, Apple IIe, Commodore 64, IBM PC, and RS-232C serial interface. It can also drive a printer and a speech synthesizer in a "stand-alone" operation.

3) Separate display screen. With a separate display screen, there is one screen devoted to keyboard use, providing the user with a large character display. The whole screen is devoted to display of user-customizable menus of commands, words, phrases, and/or characters. These menus serve as both a reminder of common commands for software packages and a method for speeding data entry.

The heart of the MOD Keyboard is a cartridge that plugs into the game slot of the VIC-2o computer. Originally the cartridge was equipped with 8K bytes of EPROM to store the MOD Keyboard program and 4K bytes of battery-backed CMOS RAM for storage of customized screen displays created by the user.

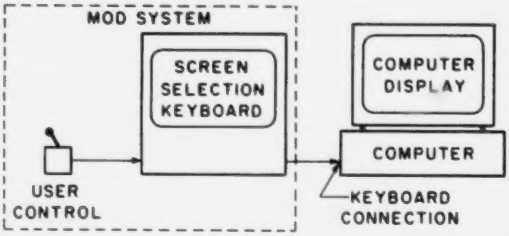

Figure 1. A diagram of the MOD Keyboard showing its position acting as an interface between the user and the computer.

The MOD System has evolved to include three different versions: the Auto-MOD Keyboard (AMK), the Elementary MOD Keyboard (EMK) and the "Clavier Elémentaire MOD" French language version of the EMK(2).

NEW DEVELOPMENTS

In order to accommodate further enhancements of the MOD Keyboard, the cartridge was upgraded to 32K bytes of EPROM and 16K bytes of battery-backed CMOS RAM with improved memory protection circuitry. These improvements have provided sufficient resources for adding a number of new features to the MOD System.

One new feature is a label editor. With certain software packages or operating systems, at times the software itself requires the user to perform seveal often awkward or difficult to remember keystrokes to execute a fairly simple operation. For instance, in Microsoft Word, to change the character format to italics, the user must press: escape, f, tab, y, return. To eliminate the need to remember this cumbersome sequence, a label feature has been added to the AMK. The user can employ a unique word or phrase as the name or label to represent the function performed by the command string. For instance, when using Microsoft Word, the label appearing on the AMK screen may be ITALICS (displayed in reverse characters). When ITALICS is selected, the string of keystrokes required to italicize the selected characters will be sent to the computer. Figure 2 illustrates the appearance of a page that includes labels.

Severely handicapped people who must use some form of adaptive input system are usually placed at a considerable speed disadvantage compared

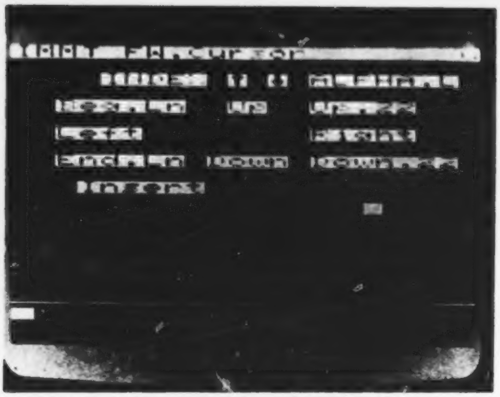

Figure 2. A screen illustrating labels for controlling the IBM PC program Friendly Writer. Note that labels appear as reversed screen characters.

to the non-disabled user of a computer keyboard. Because of this, there have been many attempts by rehabilitation engineers to devise techniques which would improve a disabled person's character entry rate. One such system is abbreviation expansion (3). For the AMK we have implemented an automatically adaptive vocabulary feature. While the user is entering a word, the AMK displays lists of words that match the current letter(s) entered. Any words entered that are not already stored in AMK's vocabulary are added to it. The words are presented on the lower half of the screen (see Figure 3) and can be selected directly by the user, usually after entering only

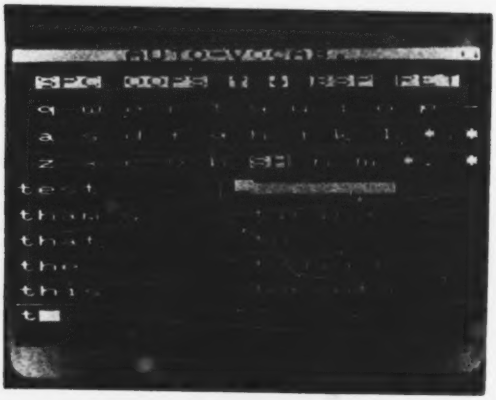

Figure 3. This screen illustrates the auto-adaptive vocabulary in operation. (The word about to be selected is "through".)

one or two initial letters. The AMK allows storage of two vocabularies each ranging from six hundred to nine hundred words. As well, a simple screen selection now adds suffixes or pluralization to selected words. A control panel screen allows the user to adjust the vocabulary features. A major advantage of the adaptive vocabulary system over an abbreviation expansion system is the fact that there is not the requirement of customization or memorization of lists of abbreviations.

All of the menus for the AMK have been upgraded to simplify their use. There are two SET-UP screens one of which requires a password for entry. Any SET-UP item may be changed by moving the screen pointer over to it, and then selecting it. The item then responds by indicating the new setting on the screen.

The Hugh MacMillan Medical Centre (HMMC), Toronto, Canada, in collaboration with the National Research Council of Canada, has developed the Elementary MOD Keyboard (2, 4). This simpler version of the MOD Keyboard was designed for use by severely physically handicapped children who are just beginning to use the computer. The characters displayed on the screen may be large and the selection pointer is brightly coloured and surrounds the item to be selected. After extensive field trials, a list of changes to the EMK has been made. Many of these changes have been implemented and will be released by June of 1987. These changes include:

1) Support for the IBM PC and Commodore 64 computers. The original EMK only supported the Apple II/II+/IIe.

2) Expanded editing facilities, including a text cursor and a delete-last-entry (oops) command.

3) Additional scanning strategies.

4) Audible feedback during scanning. These changes address the limitations found in the original EMK software.

With the increasing power of today's microprocessors, it has become possible to have one microprocessor perform more than one task at the same time. This means that for some microcomputers, it is possible to have a function similar to the MOD Keyboard performed in software that controls other programs. With a view to this end we are presently converting our MOD Keyboard features to a program that will run on the IBM PC. Written in the "C" language to improve portability and serviceability, this program operates as a stand-alone task. That is, the IBM PC is devoted to the role of the MOD System. This arrangement allows further testing and enhancements to the system, operating in the IBM PC environment. With the software AMK a number of improvements have been made over the hardware version, these are:

1) There are three character sizes (see Figure 4.)

2) All vocabulary and screen display files are stored on diskette (or hard disk) to eliminate potential file back-up problems associated with

the original MOD Keyboard's battery-backed RAM cartridge. Using diskette based storage also increases the editing capabilities of the MOD Keyboard, allowing several different text files to be edited using the MOD Keyboard program alone.

3) Since the system is being ported to the IBM PC, the MOD Keyboard may be used on one of the many portable PC-compatible computers.

4) Eventually the program will operate in conjunction with other application programs. A separate screen will be available for the user by simply plugging in a second video display card an monitor into the IBM PC.

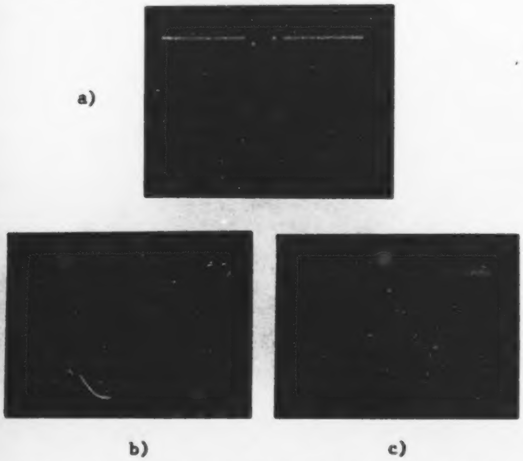

Figure 4. This screen illustrates the various character sizes available for the software MOD Keyboard: a)-small, b)-medium, c)-large.

RESULTS

The MOD System is now being used by persons with a variety of different disabilities: school children with cerebral palsy, spinal-cord injured young adults, and adults with progressive neuro-muscular diseases. After all these different users' assessments at several schools and rehabilitation centres (in particular the Hugh MacMillan Centre, Toronto), the performance of the MOD System has been improved. Although the auto-adaptive vocabulary feature requires some familiarity, users improve their communication rates by two to three times, compared to the original MOD Keyboard with words stored on indexed screen pages. One user, who had the progressive neuro-muscular disease ALS, was able to write a whole book describing her experiences with the disease... all by means of the AMK and an IBM PC as host computer (5).

After more than two years of use, the EMK has shown the value of a dual display approach to the problem of providing severely physically disabled young children with access to commercial software (6, 7). The second screen provides a simple, clear, large-character display which is easily customized to individual students and software packages. If required, the second screen can display a large number of choices (e.g. the alphabet), all in large characters. In addition, the matrix arrangement of choices means that additional selection techniques are available as options, such as directed scanning with three to five input switches.

Field testing of the EMK has led to a number of further enhancements which will be available in 1987.

CONCLUSION

The items discussed here are basically improvements to the MOD Keyboard line. One thing that has been made clear from this process is that communication between developer and the end user is of paramount importance. This relationship brings to the developer the full extent of the user's needs and to the user, the knowledge that real needs are being met.

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EFFECT OF ASSIGNING STANDARD COMPUTER KEYBOARD OPERATING CHARACTERISTICS ON QUADRIPLEGIC INPUT RATE

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ABSTRACT

Software that allows user assignment of standard keyboard operating characteristics has been commercially developed. A seperate computer program was developed to provide data on a user's ability to manipulate a standard keyboard. Data obtained on quadriplegic user's "IBM (TM) PC" computer keyboard manipulation capability is applied as parametric input to the former program. The effect of variously modified operating characteristics on the corrected input rate of quadriplegic individuals is presented.

BACKGROUND

A number of different methods have been proposed for allowing handicapped individuals to access micro-computer systems. Most approaches rely on the use of "ability switch" inputs. Both ability switch and keyboard input are typically augmented by some form of code optimization technique to maximize the effective input rate of the user (1,2,9). Other approaches to allowing access depends on increasing the "target area" of the input device, using voice for input or applying signal conditioned nervous system activity (3).

Each of the above approaches depends on, in addition to possible software drivers, extra hardware connections to the basic computer system. In addition to adding to the initial cost of the system, hardware adaptations also add to the inevitable maintenance/repair costs associated with system ownership. A software approach to micro-computer access could not only reduce initial equipment costs but would not add to the maintenance burden of the user. Software applications are typically less demanding in their hardware requirements do not consume extra power nor demand space and fixtures for their utilization.

A software package named FILCH is commercially available which allows most orthopedically/neurologically disabled individuals to access an IBM PC/XT/AT or true compatible using a standard keyboard as their only input device. FILCH is a programmable keyboard filter that allows user specification of keyboard operating characteristics. In addition to allowing one handed typing, auto-repeat control, and various audio and visual indicators, FILCH also acts as a software keygaurd the function of which is independent of keyboard size, shape or location. Requisites for FILCH utilization on any keyboard are adequate range of motion to address all keyboard locations and the ability to target a single key. The third generation product, originally introduced in 1985, comes packaged with a keyboard capability assessment program (EVALUATE), a tutorial and an editor. EVALUATE is used to provide objective graphic and statistical information on an individuals motor capability and optimum FILCH configuration parameters based on the data it obtains.

METHODS

Meaningful work on a computer can only be accomplished if the computer is given meaningful input. Thus, in the real world, the corrected throughput rate of an individual is more important than the theoretical limits imposed by their input device. Assuming the requirement to correct faulty keyboard input is the entry of a Delete (destructive backspace) keystroke and a subsequent entry of a correct character, the time required for the entry of 100 correct characters can be determined by the formula below.

$$T= 100t + 2Mt$$

T= The total time required for entry of 100 correct characters.
M= The number of mistakes made during the data entry task.
t= The time required for the entry of a single keystroke which includes and individuals reaction time, the key actuation time, the keyboard debounce period, and the time required to release the key in preparation for another keystroke.

During an evaluate session, the person being tested is prompted by visual and audible cues to enter a character using the system keyboard. The characters are pseudo-randomly presented and represent the bounds of the "typewriter" keys (1, Z, E, N, =, /) on an "IBM" keyboard. The relative elapsed times measured by EVALUATE are classified as Reaction, Debounce, and Typematic intervals: These intervals respectively represent the time from the cue to the depression of any key, the time from the depression of any key to the depression of correct key, and the time between the depression and the release of the correct key (7). The above intervals for each key and the combined times of a given interval for all keys may be represented statistically and graphically by EVALUATE, the former yields positional information while the later provides a picture of the user's general motor capability. The results of EVALUATE sessions are consistent for a given individual on a given machine.

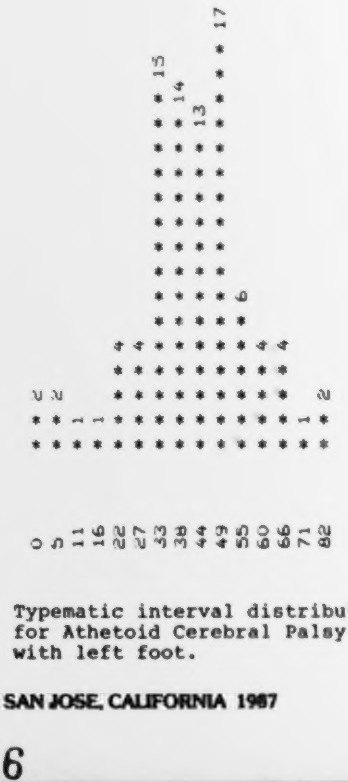
EVALUATE data on quadriplegic input was obtained using a Toshiba T-1100+ computer (15 samples of each key) and converted to sets of FILCH parametric values. Each set of parameter values was combined to provide a minimum value for "t" in the above formula while the sum of the data elements occurring above the filter cut-off time was multiplied by 1.11 and substituted for "M" in the formula. The parametric values that resulted in the minimum throughput time were thus obtained. The time values are based on the machines system clock which is incremented roughly 18.2 times per second and the values are scaled to represent 0.01 second multiples.

RESULTS

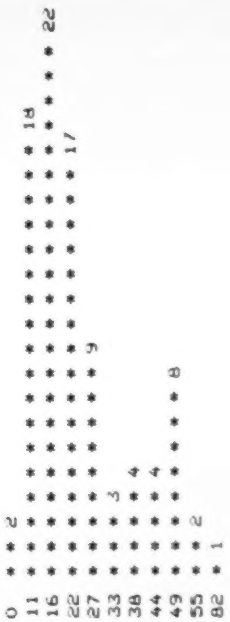
In all samples the minimum throughput time calculation was a result of the use of the parameter set consisting of the Debounce and Typematic times which had the highest product of their class time value and the number of items occurring in the class time value. This discovery prompted us to refer to the class with the maximum class*frequency cross-product as the Critical Node of a given combined time interval distribution. Each time interval has its own Critical Node. When the Reaction and Debounce time interval plots of individuals who rest their hands on the keyboard are compared to those of individuals who do not, the former's Debounce time plots resemble the Reaction time plots of the later. The parameter sets based on time interval Critical Nodes were compared to the parameter sets actually used by individuals elsewhere and were found to be consistent among a given disability classification.

The combined time distribution plots bear a resemblance to curves which represent the activity of fast and slow muscle groups (5,6). A "normal" typist's distribution profile increases dramatically in frequency in the low value time classes as the total number of samples increases; in disability classifications where slow twitch muscle cells are believed to be dominant (10), an increase in the total number of samples results in a relative decrease in the frequency of items in the low value time classes and a flatter distribution curve whose peak occurs in a much higher time value class. In all cases the "noise" level and Critical Node are essentially independent of the total number of samples.

Some factors which affect throughput are sensory in nature, independent of the system's input time characteristics and to some extent subjective (7). Particularly when extended Debounce times were applied, the use of audio feedback to indicate the transmission of valid input was found to be preferred by users. Video indicators of the various shift states were preferred by users with normal vision. For users with impaired vision, audio shift state indicators were considered useful. Additionally the extension of the auto-repeat delay interval to compensate for screen-reader output response times was applied by users who rely on these programs for keyboard input verification. The dual mode capability of FILCH shift keys was always utilized by one handed typists (8).



Typematic interval distribution plot for Athetoid Cerebral Palsy typing with left foot.



Typematic interval distribution plot for Incomplete Quadriplegic.

ACKNOWLEDGEMENTS

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CONCLUSION

It is unclear what diagnostic uses keyboard input data has, if any, or how this data relates to other findings. It is clear, however that EVALUATE can provide data which is relevant to keyboard input capability and FILCH parameter selection. FILCH has proven to be effective in allowing individuals in a variety of disability classifications inexpensive access to computers. The ability to project an individual's input capability using a standard keyboard provides objective aid in selecting adaptive input devices and documenting appropriate resource allocation.

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LOW COST HIGH TECH: COMPUTER APPLICATIONS THAT WORK

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ABSTRACT

The phrase, high tech, is often synomous with highly expensive technology, especially for individuals with special needs. In many rehabilitation clinics personnel evaluate and recommend specific technological devices for disabled individuals. Because of the expense associated with technology, many times funding cannot be located. Often the disabled individual does not have any other alternative; the only outcome is a set of well planned and written recommendations, but no computer. This paper examines technological devices available for less than $1000, discusses some examples of specific systems utilized by disabled individuals, and explores various funding sources available.

INTRODUCTION

Of the 242 million persons living in the United States, 37 million are classified as disabled. In today's society the greatest challenge disabled individuals face is gaining the freedom to work, play, and live to the maximum of their capabilities (1). Technology, a powerful tool in the lives of disabled individuals, is serving as an equalizer providing many of the same educational, vocational, and leisure opportunities as those available to able bodied individuals (2).

Today there are many products on the market designed expressly to allow disabled individuals access to computer systems. Because research and development expenses are comparable to those incurred when designing a product for the general market, the cost per device merchandized for the smaller disabled market is higher.

A one time expense may be borne easier if the device allowed maximum accessibility to a variety of systems. Many disabled individuals are encountering more than one computer brand during the span of a day: at home, at work, at school. Most devices, however, are designed for specific computer brands; a few devices, with the proper cabling, allow the freedom of interfacing to a variety of computer brands. The factor of device incompatibility adds to the expense of accessibility.

For computers to become useful tools in the lives of disabled individuals, devices and systems must be inexpensive because of the limited funding available. Oftentimes a one hundred dollar difference for a piece of equipment can make the difference whether the device is purchased or not.

BACKGROUND

While several firmware devices allowing transparent access of standard software through a variety of nonstandard keyboard input methods are now commercially available, this paper discusses three: the Adaptive Firmware Card (AFC) from Adaptive Peripherals, Inc., the MOD Keyboard from TASH, and PC AIDs from DADA.

The Adaptive Firmware Card (3,4) was one of the earliest firmware devices designed for commercial use. The AFC, available from Adaptive Peripherals, Inc. for $400.00, is designed for the Apple II+ and IIe computers and allows any of 16 input methods including scanning, Morse code, and alternate direct selection keyboards. One of many options is slowdown mode, permitting user control of a program's speed.

The standard MOD Keyboard (4,5), marketed by TASH (Technical Aids & Systems for the Handicapped) of Canada for $230.00, is a firmware cartridge that requires a Commodore VIC 20 (not included in the price). The MOD keyboard firmware inserted into a VIC 20 is basis of a keyboard emulation system which permits single and multiple switch access. While it is difficult finding a VIC 20 (available through TASH), the MOD keyboard may be interfaced with the appropriate cable to a variety of computer systems: Apple II+ and IIe, Commodore 64, and IBM PC.

The products, PC AID (Alternative Input Device) and PC Serial AID (6) from DADA (Designing Aids for Disabled Adults) of Canada, are some of the newest keyboard emulators available. Both devices provide accessibility to IBM PC, AT, XT computers and true compatibles. The PC AID at $150.00 interfaces to a parallel port and allows scanning and Morse code with one or two switches. The PC Serial AID at $250.00 attaches to a serial port and has the capabilities of the PC AID plus access through alternate direct selection keyboards.

RESULTS

The computer accessibility product does not comprise a complete system. The appropriate computer system must be added; thus increasing the costs of the complete system. Three computer systems are described; each system is available for under $1000.00 and uses a different aforementioned emulating device and a $20.00 single switch. It should be mentioned that the prices quoted are the winter 1987 prices found in retail stores in the midwestern United States. Geographical location, mail ordering, and time are variables that affect these prices.

The AFC, designed for the older Apple II series of computers, also works with the Laser 128 (7), the Apple IIc clone with an expansion slot. The Laser with a built in disk drive may be purchased for $395.00 and a monitor for $150.00. The price for the complete system including the switch is $965.00.

The least expensive method is providing assessibility with a MOD keyboard is interfacing it with a Commodore 64 (8). The newer model, Commodore 64C, incorporates the newer case of the Commodore 128 into its design, otherwise there are few changes. The Commodore 64C, disk drive, and monitor may be purchased for $460.00. Adding $500.00, the price of a MOD keyboard, Commodore VIC 20, interface, and monitor, the cost for the total system with the switch is $980.00.

The DADA devices may be interfaced to IBM and IBM true clones. With the coming of the clones, prices have dropped under the $1000.00 range. While it is difficult to locate a new IBM for this price, several compatibles list for less. One of these is the Blue Chip PC from Hyundai (9), chosen because it is sold through the larger discount retailers for $599.00. The Blue Chip has both a serial and parallel port as standard features and comes with a single disk drive. Adding a monitor and the PC AID, the complete system including the switch is $920.00

DISCUSSION

In the United States there are many sources to explore the potential of funding computer based assistive devices for individuals. The sources may be divided into two basic categories: third party reimbursement agencies and creative funding resources.

Third party reimbursement agencies include those in both the private and governmental sectors. Private insurance companies review each request for assistive devices and the determination for funding is based on need, prognosis, diagnosis, and the type of equipment requested. The terminology of the medical prescription must be precise; the computer, considered an educational not medical tool, must be labeled a medical prosthesis.

Medicare (Title XVIII of the Social Security Act) considers computers educational and does not provide reimbursement; however, Medicaid (Title XIX of the Social Security Act) funds assistive devices. Specifics may be obtained by contacting county or state Division of Family Services.

Vocational Education funds secondary, post secondary, and adult programs and funds computers utilized for training in approved vocational education programs. The Division of Career and Adult Education at the state level has specific information.

Vocational Rehabilitation, contacted through state Division of Vocational Rehabilitation, provides funds for high school seniors, adults, and school dropouts. In order to provide funding for computers, the equipment must be essential for the individual becoming employable after training, the system must be written into the individual's individualized written rehabilitation plan (IWRP), and the individual must qualify for vocational rehabilitation services.

The Bureau for the Blind will fund computer systems for legally blind individuals under the following circumstances: the individual must be a vocational rehabilitaion client and the device must be used for nonschool acitivities.

Crippled Children's Services may be contacted through regional or state offices. This agency may provide equipment for individuals whose families meet financial requirements.

Obtaining creative funding requires detective work, political savvy, and unwavering skill. A few leads in the creative funding quest include interviewing trust officers in local banks to determine the details of trusts, soliciting funds from local business or industry as part of community service or public relations programs, finding or starting a local or regional technological consortium, checking with the local chamber of commerce regarding the variety and service clubs in the area and each club's history of financial assistance for specific disabilities, and combing the State Directory of Organization Resources for the Handicapped available from each governor's Committee on the Employment of the Handicapped.

CONCLUSIONS

Because of clones and new devices, there are somewhat inexpensive options available for alternate computer access; three complete systems available for less than $1000.00 were described.

Further accessibility is needed for computers to become useful tools in the lives of disabled individuals. Financial accessibility will come with the recognition by reimbursement sources that computers are not only educational devices but have the potential to reduce costs. Physical assessibility will be available with the emulating device that allows access to a variety of computer brands through both switch and alternative direct select keyboard input.

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AN INTERACTIVE COBOL EDITING SYSTEM: KEYSTROKE REDUCTION APPLICATION FOR DISABLED STUDENTS.

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ABSTRACT

The purpose of this research effort was to design an editor for the high level language COBOL. This editor, COBEDIT(COBol EDITor), is an interactive, menu-driven software system for the IBM PC environment that will assist users in entering COBOL source code. The primary objective of this system was to reduce keystrokes for computer programming students who are disabled.[1]

INTRODUCTION

This paper presents the results of research in the area of interactive systems or interactive programming environments. Such systems are superior for programming, particularly for program debugging because program errors can be found quickly. In addition, these systems provide users with a variety of convenience features that are not feasible under a batch programming environment, such as easily retrievable documentation, help files, error detection, and error recovery services. However, system designers are more often concerned with developing an interactive system that is portable, expandable, user friendly and structurally designed.

BACKGROUND

Typically, interactive systems are syntax-directed programming environments that assist the users in creating, editing, executing and debugging programs. During the creating and editing of high level programs, these environments increase the productivity of both beginning and advanced programmers. Beginners are spared the details of the syntax of the high level language, and experienced programmers benefit from the time saved in typing code and the immediate detection of syntax errors. Furthermore, during the executing and debugging of programs, all programmers benefit from the extensive diagnostic facilities available at compilation and execution time. In short, the interactive programming environments of today have become powerful, dependable and responsive programming tools.

There are three types of interactive systems: interactive compilation systems, interactive interpretation systems and interactive direct-execution systems.

Interactive compilation systems

Interactive compilation systems employ a compiler for syntax-checking. Such systems allow the source code to be keyed in at the terminal, andan editor is employed for corrections as the source code is being entered. The main distinction between interactive compilation systems is the manner in which the compiler is employed and the manner in which the code is being interpreted.

Interactive interpretation system

Interactive interpretation systems employ neither a compiler nor an assembler, rather an interpreter is utilized to check syntax as the code is being keyed in. Such systems allow the source code to be keyed in on the terminal and a text editor is available for making corrections. There are two types of interactive interpretation systems differ in the way the source code is interpreted - one system interprets the entire source code and the other system interprets the source code line by line.

Interactive direct-execution system

Interactive direct-execution system employ a direct-execution interpreter. As each symbol is being keyed in on the terminal, the symbol is syntax-checked and executed. Users of these systems receive maximum user-system interaction, as compared with the limited interaction permitted by the other two types of interactive systems. The primary advantage of interactive direct-execution systems is its ability to assist users in debugging logical errors by displaying the partial result whenever it is requested. Thus, after keying in the entire program, the program would have executed once and could be fully debugged.

DESIGN

COBEDIT is an interactive system that assists the user in keying in ANSI '74 COBOL programs. This system is fully documented and provides on-line help at any point during the user's interaction with the editor. During the design phase of COBEDIT, the main objective was keystroke reduction. With COBOL being a tedious and a laborious language to code, a system was needed to increase the speed of code entry by disabled students; and thus, increase the students' productivity.

COBEDIT contains features from all three interactive systems described in the previous section. Although it does not possess any direct-execution features, it does check each symbol as it is being entered(a feature of Direct-Execution Systems). However, the debugging process is limited to the level of the entire source code.

---

[1] Often individuals with high level spinal cord injuries or other neuromuscular disorders exhibit a reduced ability to use a standard computer keyboard. It is not uncommon to find individuals with severe disabilities who have a maximum typing speed of 5-10 words per minute.

COBEDIT employs neither a formal compiler nor a formal interpreter; but rather, it employs a semi-intelligent "counselor". The counselor guides the user through the use of windows, system prompts. In addition, the counselor checks for careless syntax errors as code is being entered. During the entry of source code, the cursor placement is somewhat controlled by the counselor. COBEDIT decides either by convention or by previously entered source code where the cursor is to be placed. When the system is awaiting user input, the user may move the cursor to another position (relative to the line directed by the counselor) before entering any symbols. The cursor control, and the input control features are similar to that of the placeholder and template controls incorporated in the Cornell Program Synthesizer[2]. COBEDIT also employs an editor for corrections and changes as programs are being created. Again, the cursor control is governed by the counselor during corrections.

The design specifications and the features provided by COBEDIT are shown in Figures 2 and 3.

Design Specifications

Implementation Language	-Better Basic by Summit Technology.
Data Structures	-Static and Dynamic Arrays
Environment	-IBM PC/XT, IBM PC/AT or IBM compatible PCs.
System Requirements	-512K, 640K preferred, -Color Graphics Card -Two Floppy Drives or One Floppy and One Hard Drive

Figure 1.
Design Specifications

Features

Language Directed	-variable maintenance -reserved words index -variable expansion -COBOL verb descriptions (on-line)
Interface Directed	-keystroke reduction -on-line help windows -cursor assistance for input -line editing -symbol checking -error messages -source code backup

Figure 2.
COBEDIT Features

CONCLUSION

At this stage in the development of COBEDIT, data can only be gathered for assessing keystroke reduction. Based on a simple, undocumented 84 line COBOL program, the user pressed 921 keys while the system provided 1775 keystrokes. There was no provision for editing during this data collection exercise. It was assumed that the person was flawless in the typing of the sample program.

As a result of this very basic demonstration, the user saved 66% of the total keystrokes. This savings may be unrealistically high, however, it is anticipated that the user of this system will realize at least a 50% reduction in keystrokes. COBEDIT's method of keystroke reduction is illustrated in Figure 3(i) and Figure 3(ii). In both figures, the characters/words that are not underlined, are provided by COBEDIT.

```
IDENTIFICATION DIVISION.
PROGRAM-ID.      CONFLAB.
AUTHOR.          JOSEPH HUANG.
INSTALLATION.    LTU-BIOMED.
DATE-WRITTEN.    JUNE 21, 1987.
```

Figure 3(i).
IDENTIFICATION DIVISION of a sample COBOL program.

```
MULTIPLY PRINCIPAL BY SIMPLE-INTEREST-RATE
    GIVING INTEREST.
ADD INTEREST, PREVIOUS-BALANCE
    GIVING NEW-BALANCE.
```

Figure 3(ii).
A COBOL program fragment.

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[2] The Cornell Program Synthesizer is a highly sophisticated interactive programming environment with integrated facilities to create, edit, execute, and debug programs. Currently, the Synthesizer is being used to teach PL/CS, an instructional dialect, at Cornell University. Readers are asked to refer to [3] and [5].

Counting the underlined characters and the non-underlined characters in Figure 3(i), and Figure 3(ii), one can realize a 64% and a 82% reduction in keystrokes, respectively. It should be noted that in the second figure, the user has the option of keying only a fragment of the word or symbol and the system will provide the remaining letters. However, in both figures, the actual percentages will depend on the number of keystrokes the user provides. Furthermore, the reduction of keystrokes will vary across COBOL statements and will vary depending on the length of the entire source code.

This is the first version of COBEDIT, therefore, refinements and enhancements will certainly be necessary. It was developed for disabled students to reduce keystrokes. A keystroke reduction system will not only benefit disabled students, but will also benefit non-disabled students. Therefore, a system such as COBEDIT could become an important programming tool.

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KEYBOARD EQUIVALENT FOR MOUSE INPUT

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ABSTRACT

Operation of a computer and application software is becoming dependent on the ability to use a mouse. This makes it impossible for many disabled individuals to use these computers. A possible solution is to provide a keyboard equivalent for mouse input. This is a reasonable approach since there are already many ways for the disabled individual to use a keyboard or emulate keyboard input. However, it is not enough nor always easy to accomplish the technical aspects of this task. Human factors engineering approaches must be used to make the keyboard emulation of the mouse as intuitive and as easy to use as possible, and future operating systems need to be designed to make implementation of this solution feasible.

INTRODUCTION

There is clear distinction between the purpose of the physical mouse on the table top and the purpose of the pointer on the screen. The mouse is a device used by the operating system to move a pointer on the screen and to provide certain events (button down/up, clicks) as input to programs. Programs are interested in the position and motion of the pointer when other actions occur, and not the exact position or motion of the mouse.

This distinction is very important since we are trying to emulate the types of information a program expects from the use of a mouse, and not the physical mouse. If we try to emulate the physical mouse, we are two steps removed from what the program wants.

RESULTS

We found that implementation of a keyboard mouse (Mouse Keys) should use the numeric keypad for two reasons:

1) it allows other keys (including cursor keys) to remain active while using Mouse Keys,
2) and it provides intuitive directional key layout.

We also discovered that there should be the following features:

1) smooth motion of the pointer,
2) single pixel motion by tapping the keys,
3) slow constant acceleration of the pointer up to a maximum speed when the keys are held down,
4) adjustable maximum speed and acceleration,
5) lower maximum speeds for individuals with slower key release times,
6) single click and button down and up functions.

We also discovered the following:

1) the velocity in the diagonal directions does not have to be the same as in the orthogonal directions but can be made up of the vertical and horizontal components,
2) it is useful to have hyper screen and window motion modes,
3) it is useful to have double, and triple click functions,
4) and it is useful to have an adjustable initial step.

DISCUSSION

Goals of a good design

The goals of a good design are 1) to provide the same information that the mouse provides to the programs, namely pointer position and motion, and button events and 2) to provide a good human-machine interface.

Which keys to use

The two consideration in determining which keys to use are 1) which keys provide the most intuitive interface to moving the pointer around the screen and 2) which keys are duplicated by others so that with Mouse Keys enabled, the user can still operate the software.

The numeric keypad is a very good choice since the key layout provides an intuitive set of keys for moving the pointer in eight direction, and most of the numeric keypad keys are duplicated by other keys on the keyboard.

Enabling mouse keys

The method for enabling Mouse Keys needs to satisfy the following guidelines:

1) no other program should expect the same sequence of keystrokes,
2) and getting out must be logically related to getting in.

For instance, on an IBM PC, if an "alt-m" (alt-mouse) enables Mouse Keys then "alt-k" (alt-keyboard) should disable Mouse Keys. If "ctl-alt-numlock" is used for enabling then just a "numlock" or another "ctl-alt-numlock" should be used for disabling. On a Macintosh, a command-shift-clear might be used. The danger of using the exact same key combination to enable and disable is that it can get very confusing. It is then difficult to determine if Mouse Keys is enabled or disabled unless there is some indication of the state.

Smooth versus jumpy pointer motion

The pointer is meant to represent a physical object on the screen and physical objects move in a smooth and continuous fashion. Jumpy motion of the pointer is therefore undesirable since it makes the relation of the pointer to the desired motion less intuitive. The motion of the pointer using Mouse Keys should maintain this characteristic. A smooth moving pointer also gives immediate visual feedback as to the position, velocity and acceleration of the pointer so accurate prediction of its location upon release of the keys is easier to make.

The keyboard is a discrete event device, so the most natural way to implement pointer motion using the keyboard is to move the mouse every time there is a key, or a key-repeat. This would produce a smooth motion if the pointer moved only a few pixels per key. However, with this method it would take a long time to move across the screen for users with a slow key repeat rate.

A good way to get around this problem is to use the initial down stroke of the key to move the pointer one pixel (thus always giving very accurate control) and as soon as the key starts to autorepeat, the pointer should start moving in a smooth motion, first slowly and then faster until it reaches a maximum speed. As soon as the key is released, the cursor should stop. The reason it should start off slow and then get faster is due to the fact that the amount of time it takes a person to recognize the cursor is moving and then release the finger is not instantaneous. If its motion starts at the maximum speed then it is very difficult to move the pointer a short distance.

Use of the auto repeat feature

The key repeat delay is the time after the press of a key before the auto repeat starts. It will be assumed that an individual adjusts (if possible) the Delay so that the he/she can consistently and easily press and release a key and get only only one character each time.

The key repeat interval is the time between the auto repeat of the keys. It is assumed that the repeat interval is adjusted so that the individual when trying to get a certain number of characters using the auto repeat will consistently get within one of the desired number. This means that they are able to position the cursor within three repeat interval values. We will assume that the consistency of accomplishing this is 99.7%. This means that 99.7% of the attempts will produce results that fall within three standard deviations (based upon the theory of normal distribution).

Determination of maximum speed of pointer motion

The maximum speed of the pointer is very dependent on the physical ability of the user. In determining the maximum rate of speed the key repeat rate must be taken into account. If the repeat interval is 0.1 seconds (i.e. 10 characters per second) and the pointer is moving at 100 pixels per second, then the user is able to accurately release the key within 0.3 seconds 99.7% of the time, thus placing the pointer within +/- 15 pixels. If an accuracy of +/- 5 pixels is desired, then the maximum speed must be set to 33 pixels per second.

This was confirmed by experimentation which is summarized in Table 1. Although there seem to be some inconsistencies with the theory, they can be explained as follows. Subject 2 showed poor correlation due to the fact that when setting the repeat interval, the next faster speed (4/60 sec) was not selected since it was just a little too fast. Subject 4 showed high positive average error due to the inability to predict the motion of the pointer. The subject would not attempt to release the key until after seeing the pointer at the target. Subject 5 showed poor correlation since the computer could not have the repeat interval set any slower than 12/60 second without going to an incredibly slow rate (144/60 second). Subject 7 showed poor correlation due to a problem with maintaining concentration in the task. The subject several times forgot to release the key because the subject's inattentiveness. This is shown in the high positive average error.

These results indicate that the ability to use Mouse Keys at the maximum speed depend not only on the consistency and speed of the physical release time of the key but also on the individual's reaction time and motion prediction ability.

In determining the desired placement accuracy, a small enough value should be chosen to meet the nominal required accuracy of the placement of the pointer by the system or application software, which tends to be between three and five pixels. Requiring that six standard deviations of consistency be used is based upon the fact that individuals get easily and quickly fatigued in using pointing devices if they constantly over- or under-shoot the desired location on the first attempt and have to try again. Therefore, accuracy of placement of the pointer on the first attempt should always prevail over the desire to move the pointer quickly over long distances.

Determination of pointer acceleration

There are two simple ways of implementing acceleration of the pointer: constant and linear acceleration.

We discovered that a constant acceleration approach works the best since it is the most familiar and thus induces less cognitive load. In the task of estimating the time of arrival of an accelerating object, people are most familiar with the motion of objects in the air. Objects moving in the air are subject to constant acceleration (gravity) and so we are very accustomed to estimating the arrival of an object (baseball) to a point (the mitt) when the object has constant acceleration. Constant acceleration also provides sufficient gradation of motion from initial to final velocity to provide accurate placement of the pointer to close distances.

We discovered that the critical factor in determining the acceleration was fairly independent of the individual's speed at using the keyboard. Most individuals preferred the time it took for the pointer to reach the maximum speed to be somewhere between 3 and 4 seconds. The limiting factor depends on how quickly and comfortably the mind can accurately predict an accelerating object's location.

Directional dependencies

Although there were some differences in the accuracy and standard deviation in the different directions for each user (see Table 2), there were no clear patterns nor any consistency (e.g. subject 5 was able to move to the right more accurately than to the left, but subjects 3 and 6 were not able). Therefore it does not seem appropriate to have an implementation of Mouse Keys allow for variation in maximum speed and acceleration depending on the direction of motion.

Uniform speed in all directions versus in orthogonal directions

At first it was thought that the pointer should move at the exact same speed in all directions even though from an implementation standpoint it is easier to maintain the same speed in just the orthogonal directions and let the diagonal directions be faster by 41% (square root of 2). However, we found that even though a uniform velocity tends to allow more accurate placement in the diagonal directions, the accuracy of placement with non-uniform speed in the diagonal directions was no worse than in the orthogonal directions (see Table 3). This is because the maximum speed is optimized for the orthogonal directions and the error is based on

Subject No.	Key Repeat Delay (1/60 sec)	Key Repeat Interval (1/60 sec)	Maximum Speed (pix/sec)	Average Error (pixels)	Standard Deviation	Predicted Standard Deviation	Error %	New Recalculated KeyRepThresh
1	16	2	180	0.41	2.86	3.00	-4.7	1.91
2	16	8	40	0.17	1.70	2.67	-36.3	5.10
3	24	12	30	0.48	2.81	3.00	-6.3	11.24
4	24	12	30	2.36	3.08	3.00	2.7	12.32
5	24	12	25	2.30	2.98	2.50	19.2	14.30
6	40	12	20	1.71	2.30	2.00	15.0	13.80
7	40	12	20	4.75	2.66	2.00	33.0	15.96

Table 1

Subject No.	Up Average Error (pixels)	Up Standard Deviation	Down Average Error (pixels)	Down Standard Deviation	Left Average Error (pixels)	Left Standard Deviation	Right Average Error (pixels)	Right Standard Deviation
1	0.51	2.13	1.45	2.43	0.43	2.17	0.34	3.02
3	1.00	2.90	*	*	-0.33	3.56	0.67	3.67
5	2.00	1.95	1.08	2.71	1.75	1.82	0.04	2.97
6	2.00	2.53	1.00	1.10	1.17	4.12	1.75	2.96

Table 2

pixels in the orthogonal directions rather than distance in the diagonal direction.

Optional initial step motions

It was assumed that all users are able to use the auto repeat feature. However, this might not always be the case. If the auto repeat feature is off, Mouse Keys should allow the initial step to be adjusted to values other than one. This way, the user who is not able to use the auto repeat (due to very slow release times and erratic release times) and has disabled it, can move quickly across the screen by setting the initial jump to five or ten pixels per key press. This feature also lets all users make accurate long movements without having to tap the key many times. For example, to move exactly 100 pixels to the right, normally one would tap the "6" key 100 times. But if the initial jump were set to 10, then one would need to tap the key only 10 times. The initial step could be set by first typing the "set key" and then one of the number keys with "0" being equal to 10.

Hyper modes

After use of Mouse Keys, it was found that two modes called screen-hyper and window-hyper function would be very helpful. The screen-hyper function allows the pointer to jump to the center, or near to the edges or corners of the screen. A simple way to provide this is to have a screen-hyper key which when pressed before a direction key, makes the pointer jump to the edge of the screen in the relative directions or to the middle of the screen if the "5" key on the numeric keypad was pressed. This would be very useful to quickly move around on the screen. If the computer system has menu bars at the top of the screen the screen-hyper function makes it very easy to get to the menu bar. The window-hyper function is identical to the screen-hyper function except that the pointer would jump relative to the current window under the pointer. Again, if there are significant areas near the edge of the window (e.g. title bar, close box, scroll bars, size box, zoom box, etc.) then this feature makes it very easy to quickly move to those locations.

Difficulties in implementation

The following list of features of an operating system that would greatly facilitate implementation of Mouse Keys is based on our experience trying to implement Mouse Keys on the IBM to work with Microsoft Word and Windows using Microsoft's serial mouse, and on the Macintosh computer:

1) There should be a well defined way to hook into keyboard events and to inhibit or pass them on. From this hook, it should be possible to have access to the full computer (i.e. the keyboard hook should not be at interrupt time). This hook should be early enough in the chain to be able to distinguish as many keys as possible and before the key is passed to the operating system and application program.
2) There should also be a way to hook into the real mouse input (again not at interrupt time) in order to "OR" button information with mouse key buttons or to inhibit real mouse information all together.
3) There should be a defined way to inject multiple mouse events (motion and button action) and to set the position to absolute or relative position on the screen.
4) The routines that draw the pointer should not occur at mouse interrupt time but after the translation of mouse motions into pointer positions.
5) There should also be a mechanism to get CPU time intermittently, preferably every vertical retrace of the screen, in order to create a smooth moving pointer.
6) The mouse and Mouse Key routines should be able to work from the same pointer position so that either of them can move the pointer at the same time or alternately.

Subject No.	Uniform Average Error (pixels)	Uniform Standard Deviation	Non-Uniform Average Error (pixels)	Non-Uniform Standard Deviation
1	0.31	1.66	0.49	2.74
3	-0.50	2.26	0.56	1.81
5	0.50	2.72	0.17	2.24
6	-0.58	2.84	2.50	1.78

Table 3

CONCLUSION

Mouse and graphical based computer systems are praised for their ease of use and intuitiveness. These benefits should not be limited to only those that can use the physical mouse. The Mouse Key solution can be easily implemented on future computers with some fore thought in the design of the computer's operating system.

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ALTKEY: A SPECIAL INPUTS PROGRAM FOR THE IBM-PC

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ABSTRACT

A scanning program has been developed for the IBM-PC and PC-compatibles that gives a user operating a single switch access to virtually all commercial PC-compatible software. This program, called ALTKEY, allows the user to reproduce all the single and multiple key combinations available on a standard PC keyboard. It is invisible to application programs and does not interfere with normal functioning of the keyboard. Scanning choices are presented to the user on a single line of the video display and are selected with one of the keyboard shift keys or with a switch connected to a standard game port button. Each selection by the user may display a new set of choices or send key codes to the keyboard buffer or both. Scan choices are arranged in an arbitrary number of scan levels. The structure of this scan tree is described in a simple ASCII text file which can be edited by the user. A new scan tree definition may be loaded as often as desired, allowing the user to customize the scan tree for different application programs.

INTRODUCTION

For several years the personal computer has been a primary tool for allowing the severely disabled to communicate with and control their environment. In the past the device chosen most often for these applications was a member of the Apple II family of computers. These machines provide an attractive compromise between power and cost and have available a large body of software addressing the full range of computer applications. The handicapped user needs access to this commercial software but must control it with methods other than the standard keyboard. These alternative input methods may include head pointers, joysticks or special switches, but they are all designed to emulate input from the keyboard. The most successful device for adding special input options to the Apple II is the Adaptive-Firmware Card (AFC) made by Adaptive Peripherals [1]. This interface is programmed to allow the user to enter information using a variety of methods. These include one- and two-switch scanning and Morse code.

The IBM-PC and PC-compatible computers have become the standard personal computers in business and science, largely because of their superior processing power and memory capacity. Steady decrease in system cost has made them an excellent choice for the handicapped user. The ALTKEY Keyboard Emulator is a special input driver for the IBM-PC. It is designed to solve the same problem in software that the Adaptive Firmware Card solves in hardware on the Apple II. It augments the device driver software already present in the computer in the basic input/output system read only memory (BIOS ROM) by adding a scanning system which allows each user to design and edit individual scan menus. Input generated by this system goes to the regular keyboard buffer where it is treated as actual keyboard data.

METHODS

ALTKEY presents the user with a series of input choices listed across one line of the video screen. These choices are highlighted one at a time in a repeating pattern. The user makes a specific choice by activating a switch when the desired entry is highlighted. The switch can be one of the shift keys on the keyboard or a momentary switch connected to a game port input. Each selection can display a new set of choices or send key codes to the keyboard buffer or both. The list of branching menus and entries is called a scan tree. The scan tree is defined in a simple text file called a scan tree definition file. The user can create and edit these files, customizing them for specific application programs.

The ALTKEY system is composed of two programs. The first, called AKSCAN, is executed once each time the computer is reset. It becomes resident in memory and contains the code that implements the actual scanner. The other program is named ALTKEY. It parses the scan tree file and loads the condensed representation of the scan tree into the internal buffer used by AKSCAN.

AKSCAN

When AKSCAN is executed it installs itself in memory, allocates a storage buffer for the scan tree (default 16 kilobytes) and then inserts new interrupt service routines into four of the BIOS ROM interrupts. These include the video interrupt, the timer tick interrupt, the keyboard service interrupt and the keyboard request interrupt. Old interrupt routines are not disabled but are instead controlled by the scanner. AKSCAN then exits but signals the operating system that the memory it occupies should not be used for other storage, leaving the scanner code resident.

The AKSCAN scanner remains dormant until ALTKEY activates it by loading a scan tree into the storage buffer. During operation the scanner takes over one (user chosen) line of the video display. Scan timing is controlled by counting the timer tick interrupt which occurs 18.2 times each second. The user can define many of the scan parameters including scan tree design, display row and scan speed.

ALTKEY

ALTKEY's primary purpose is to load scan trees into memory. It can also be used to disable the scanner either temporarily or permanently. Disabling the scanner temporarily allows the selection switch to be used by other programs. Although not normally necessary, the scanner may also be permanently disabled, effectively removing it from the interrupt response chains (without rebooting).

To load a new scan tree the user executes ALTKEY with the scan tree file specified on the command line. This causes the program to read through the file to convert the scan tree definition from English mnemonics to the numeric function codes used internally by AKSCAN. Any errors discovered in the syntax of the scan file are reported to the user. If there are none, ALTKEY establishes communication with the resident scanner through the keyboard request interrupt and loads the completed scan tree into the scanner's buffer.

Scan Tree Definition File

Much of the power of the ALTKEY system derives from the flexibility in scan tree design afforded by the scan tree definition file structure. This file is composed of a list of items. There are six distinct types of items and these types may be mixed in nearly any order within the scan file. The six types are:

```
initial:[action seq]:;

group:[display]:[action seq]: { [other items] }

entry:[display]:[action seq]:;

hold:[hold time]:[action seq]:;

file: "filename" :;

* This is a comment and is ignored.
```

Each item is recognized by the first word, called the type identifier. One or more information fields follow the type identifier. These fields are delimited with colons. The end of each item (except the group item and comment lines) is signalled by a semicolon. The bulk of the file is made up of group and entry items. In the tree analogy these two correspond to branching nodes and terminal nodes respectively. Their information fields have the same functions. The screen display field holds the literal text which will appear in the scanner menu for that item. ALTKEY assembles all the screen display fields from a group to create the scan line menu of choices. The action sequence can be a mixture of simple text and special action codes. These action codes are predefined and are contained within brackets consisting of greater than and less than signs. Several examples of action codes are listed below.

<ctrlc>	send Control-C to the buffer
<row12>	put scanner on screen line 12
<quiet>	disable audio feedback
<stop>	turn off the scan line

In operation the scanner begins at the top of the tree and shows the display fields for the first scan menu. It highlights these fields one at a time. The user waits until the desired selection is highlighted and then activates the selection switch. ALTKEY responds by executing the action sequence associated with that display field. This can have several effects. Normal text within the action sequence is sent to the keyboard buffer and appears to application programs to have come from the keyboard. Some action codes such as <ctrlc> also send text to the buffer; others such as <stop> are designed to accomplish some special action. An action sequence may be a mixed string of text and action codes.

When an entry item is selected the scanner executes the action sequence and then scanning starts again from the top of the scan tree (or any preprogrammed location). When a group item is selected the action sequence is executed but then the next scan menu that appears is composed of the entries and groups which are listed within the paired braces which follow the group item, essentially moving down to the next scan level.

The three remaining types of items, initial, hold and file, have special functions. An initial item is followed by a single information field, an action sequence as described above. This sequence is executed by the scanner once at the time the scan tree is loaded by ALTKEY. This provides a method to set scan conditions.

The hold item allows the user to select and execute an action sequence in the same way that entry and group items do. But this type of item is selected by holding the selection key down for a prescribed minimum time. The first field is not a display field but a number which indicates how many timer 'ticks' the switch must be depressed in order to select the item. This can be used to provide a safety net. If the following item is routinely included in scan tree definitions:

```
hold:100:<reset>:;
```

the user is protected from most programs that may accidentally get caught in an unknown state or loop. To escape from this situation the user need only hold down the selection switch for about 5 seconds (100 timer 'ticks'). After this hold the scanner will execute the action sequence, <reset>, which will in turn initiate a system reset.

The file item also has a single information field. In this case the information is the name of a disk file surrounded by double quotes. This causes ALTKEY to open the named file and insert the text of that file into the text of the main scan definition file at the point where the file item occurs. The effect is the same as a macro expansion in assembly language. This mechanism allows the scan tree designer to place favorite subtrees in separate files and then reuse them frequently without having to include the complete text of the file each time.

DISCUSSION

A keyboard emulator must be invisible to the application programs it will be used with. This goal involves both input from the keyboard and output to the screen. On the input side ALTKEY replaces the system keyboard buffer with a larger buffer (128 bytes) used for input from both keyboard and scanner. The larger buffer allows the scanner to send a lengthy text string (such as a name and address) to the buffer with a single scan selection. Text is retrieved from this buffer by application programs using the standard keyboard request interrupt.

Ideally all output to the screen should be routed through the standard system video interrupt routine. Many programs, including MS-DOS and PC-DOS, actually do use this method of screen access. ALTKEY intercepts each of these calls and makes sure that its own scan line does not interfere with the standard video processing. Unfortunately this does not solve all the video collision problems. A growing number of programs (including ALTKEY) access video memory directly, completely bypassing the video interrupt. When this occurs ALTKEY has no way to intercept the action. The result is that occasionally one or two lines of the screen may become slightly jumbled as output from ALTKEY and the application program mixes unpredictably. This rarely impinges seriously on functionality.

In addition to transparency a useful scanner must give access to as large a percentage of the available keyboard keys as possible. On the standard PC keyboard there are 84 keys. Each of these can also be combined with one of three different shift keys. ALTKEY can imitate virtually all these choices in one of two ways. Some special key combinations have explicit action codes. Examples of these are listed above under METHODS. The other way to produce key combinations is a more general one. The user can combine the action code for a shift key, <alt...>, with one of the two action codes, <...next> or <...lock> to produce a composite which will apply that shift key to future key codes. For example, <ctrlnext> means combine the Control key with the next key code generated by the scanner.

ALTKEY goes several steps beyond a basic one-switch scanner. The addition of a tree-structured scan definition file which can be reloaded whenever needed has an important impact on efficiency for the user. At its simplest level this allows the individual user to customize menus to personal taste.

The scan tree can be used to decrease the number of scan selections necessary to accomplish a task, especially one which involves making the same choice several times in succession. Moving the screen cursor down 10 lines on the video display using the down arrow key is a good example of this type of task. With a conventional scanner it would be necessary to complete the entire down arrow selection process 10 times. This could be handled in ALTKEY more efficiently by programming the menu containing such cursor movements to repeat scanning until an "escape" is actively chosen.

A still more powerful use of the scan tree construct involves designing the scan tree to follow the input modes and choices expected by an application program. This is very effective for most word processing programs. At each step in these programs the user is presented with a menu of choices. Each selection from this menu takes some action and then presents a new menu based on the previous choice. This is exactly the way ALTKEY presents scan menus. With a scan tree definition file written to mimic a specific program the choices displayed in the current scan menu will always reflect the responses expected by the program at that time. A new scan tree may be loaded into the scanner whenever necessary, making it practical to have a special scan tree definition file for each application.

ALTKEY has been tested with quite a number of commercial programs with good success. It will work properly with virtually all non-resident software. The one group of non-resident programs where it fails is those programs that run the display screen in graphics mode. A major example of this is REFLEX: The Analyst by Borland International.

Memory-resident programs can present more of a challenge to ALTKEY. Here again it will work with most other software but it is important to load the different resident programs in the correct order. ALTKEY should be loaded first since it controls the keyboard service interrupt and maintains the actual keyboard buffer. With this procedure it will co-exist with many keyboard enhancement programs such as Prokey by RoseSoft.

FUTURE WORK

ALTKEY is the basis for an efficient system to control a PC-compatible from a single switch. Work to date has concentrated on developing the scanner programs themselves. The full power of the system can only be realized with well-designed scan tree definition files which take advantage of the available features.

Work is currently underway to add Morse Code and two switch scanning as an option anywhere in the scan tree. Modification of the program so that it will function with software which uses the graphics mode is also planned.

NOTE

This paper is an update of work first reported in the Proceedings of the 8th Annual Conference of the IEEE Engineering in Medicine and Biology Society.

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COMPARISON OF THREE PC-XT BASED VOICE RECOGNITION SYSTEMS

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ABSTRACT

A project was initiated to develop and to evaluate, clinically and technically, a radio transmitter linked, voice controlled workstation for the high level quadriplegic. Commercial voice recognition systems were evaluated from Texas Instruments, Votan and Roar Technologies in a PC-XT compatible computer for their suitability in workstation applications. The systems were assessed for recognition accuracy, vocabulary sizes, host system memory requirements, keystroke output capabilities, vocabulary booting capabilities, vocabulary training procedures, vocabulary switching techniques, synthesized and digitized speech response capabilities, availability of telephone manager hardware and general product support.

INTRODUCTION

Interfacing an individual with a high level spinal cord lesion to a technical aid requires that sufficient functions be provided to the individual while access speed is maximized and frustrations in using the system are minimized. For those functions that could be based around a computer workstation, the use of voice recognition technologies may allow a faster and more direct approach to providing input to the workstation than presently available switch and scanning input methods. A number of voice recognition systems are commercially available but many are limited in their workstation applications for the disabled due to the limitations of the host computer. For this reason only voice recognition systems that could be used with IBM PC compatible computers were considered since these computers are readily available with 640K of system memory and optional hard disk storage media. However, it is often difficult to determine from brochures on voice recognition systems what all the features of the systems are and what are the system's limitations. It is even more difficult for the clinician to analyze the specifications of voice recognition systems and determine which system provides the features appropriate for a particular individual's needs. This paper describes the voice recognition systems' features, the evaluation procedure and the results of the evaluation. The results indicated that the selection of a voice recognition system is strongly influenced by the particular application for which it is required. Some suggestions are provided that may serve to guide clinicians in choosing particular voice recognition systems for their applications.

BOARD FEATURES

Vocabulary Sizes

A vocabulary is defined as a set of phrases, voice templates and keystroke responses. The phrases are the actual utterances which the user will speak into the system. The utterances are digitized by the voice recognition board and the resultant of this process forms a voice template which will be used in a template matching process for recognition with future utterances. The keystroke response is the sequence of keystrokes generated by the voice recognition board, as a transparent keyboard, in response to a recognized phrase. More than one vocabulary can be loaded into the computer memory but only one is active at a given time. Vocabularies in memory can be interchangeably accessed by the voice recognition board through voice commands, with access delays between vocabularies of approximately a second. A large number of vocabularies can be stored on a hard disk since a typical vocabulary requires approximately 20-30K of storage space.

Methods of Recognition

There are two commonly used methods for voice recognition, discrete and continuous recognition. Discrete recognition begins digitizing the sound input once a certain threshold voltage has been exceeded and stops digitizing when the input sound level causes the voltage to fall below the threshold voltage. The sound envelop between the crossings of the threshold voltage is evaluated against the stored voice templates for a match. The sound envelop must fit within a certain time window to be considered as a valid sound input. This also means that deliberate pauses must be made between each utterance and that no utterance may exceed that time window. Continuous recognition continually scans the incoming sounds and applies the time window without waiting for the minimum threshold voltage to be crossed. The user does not need to pause between utterances and can input voice commands at a more rapid rate than discrete recognition systems. The main deficit of continuous recognition results when portions of longer phrases can be matched to shorter phrases within the vocabulary causing misrecognition. Voice recognition systems which have large immediate vocabularies use discrete recognition to improve recognition accuracy.

Training Procedures

For the quadriplegic using voice input to a computer, it is important that developing, training and retraining vocabularies be accomplished with as little actual keyboard input as possible. The way in which typical users pronounce phrases changes slightly from day to day due to various physiological factors. These changes sometimes affect recognition to the point where some phrases have to be retrained. It is time consuming if retraining requires exiting the application program, loading the vocabulary editor, retraining the phrase(s), exiting the editor and reloading the application program. Dynamic retraining allows problematic phrases to be retrained from within the application program "on the fly". The Texas Instruments system was the only system that could be completely trained with voice commands while the Voicekey system was the only board that allowed dynamic retraining.

Telephone Managers

Both Texas Instruments and Votan have optional boards that piggy-back their voice recognition boards to perform telephone management functions. The telephone managers typically can operate as telephone answering machines and can store telephone number lists for later retrieval and automatic dialing. Another feature of the telephone manager allows input to the voice recognition board via a standard telephone handset. An extension of this input method allows standard cordless telephones to be used for remote voice entry. This remote input method must be capable of providing the user with feedback, indicating whether the computer is responding appropriately to the commands given.

The Texas Instruments system was the only telephone manager which allowed total voice control over answering the telephone and dialing telephone numbers using the speaker and microphone combination as a speakerphone. The telephone manager software ran as a background program and could be pulled overtop of an application program, such as word processing, to access the telephone functions without exiting the application program. The cordless telephone could not be used for remote access to the workstation when the telephone manager software was activated.

METHODOLOGY

All three of the voice recognition boards were directly pluggable to the IBM bus and therefore were internal to the computer case. The interrupt vectors used by the voice recognition boards were sometimes at the same vector preventing more than one board from being plugged into the computer at one time without conflict. Connection jacks were accessible from the back of the computer for interconnecting microphones and, if the features were available, for external speaker, telephone line connection and telephone handset connection.

Each of the boards had different vocabulary size capabilities but to test the recognition accuracy of the board a standard vocabulary was developed. The standard vocabulary was based on the phonetic alphabet which represents the letters A,B and C by the spoken phrases ALPHA, BRAVO and CHARLIE. Each letter in the phonetic alphabet has a distinct sound characteristic which is different from the very similar sounds of the letters B,C,D and E. As vocabulary space permitted for each board additional phrases were added to reach the maximum vocabulary specifications. The additional phrases represented frequently used keystrokes such as the numeric, punctuation and function keys. The vocabulary was then trained into the system and tested for performance. The software for each of the voice recognition boards had a test facility built in which indicated the recognized phrase and a relative score associated with the recognition. If any of the phrases were identified as having a low recognition rating, the phrase was retrained. If the tests showed that a phrase was frequently misrecognized for another phrase in the vocabulary an alternate phrase was chosen. Such a conflict was observed between the DOS command DATE and the numeric phrase EIGHT. Wherever possible phrases were chosen to be representative of the function that they were intended to perform.

Once the trained phrases were performing reliably, the complete vocabulary was tested three times consecutively. The test score for each phrase was noted if correctly recognized, if a second phrase recognition choice was indicated, if no phrase was recognized and if the phrase was misrecognized the actual recognized phrase was noted. It should be observed from the test procedure that the boards with smaller immediate vocabulary capacities have an accuracy advantage over those boards with larger immediate vocabularies since there are fewer phrase templates to match and therefore less possibility for misrecognition. Higher recognition accuracy is not necessarily indicative of a better board for workstation applications, since there are many other factors to be considered in the overall performance of the system.

RESULTS

All boards demonstrated good recognition accuracy with the tested standard vocabulary. Accuracy of recognition seem to be quite dependent on microphone positioning. Best performance was obtained when the microphone was placed to one side of the mouth. Repositioning of the microphone from one session to another was critical. The effects of this factor can be reduced by the use of a telephone handset for input since the mouthpiece is mechanically repositioned by the shape of the handset. As voice recognition was used with a number of programs in a simulated workstation environment, it became apparent that the number of phrases immediately available to the user had a more significant affect on performance than recognition accuracy. Smaller immediate vocabularies resulted in some phrases, especially vocabulary switching phrases, being duplicated a number of times. Additionally the smaller vocabularies required an utterance to select the appropriate vocabulary and a second utterance to obtain the desired keystroke output.

During the course of the tests it became necessary to change computers to another compatible computer. The difference in the inherent electronic noise present in the computer required that all vocabularies had to be retrained to achieve the same recognition accuracy. This factor would be important if a disabled individual planned on transferring his voice card between a computer in his work environment to a computer in his home environment.

CONCLUSION

If voice recognition is only to be used to output keystrokes to the computer, the Voicekey card proved most versatile with its 512 word vocabulary and using only 26K of computer memory. The purchase price was also the lowest.

If hands free telephone management was an issue, the Texas Instruments system was the only system that could perform this. The researchers had some bad experiences with two hardware failures on this system and a total lack of product support from the supplier, TI Canada and TI in Texas. This needs to be a consideration in the final system decision.

If digitized messaging feedback was required in response to each recognized phrase, the best system for this is the Votan. This type of feedback would be required if remote accessing were to be used.

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A COMPUTER INTERFACE FOR THE DISABLED BASED UPON A CODE OF VECTORS RELATED TO USER MOTION

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ABSTRACT

A new human-to-computer interface for the disabled is described in which user choices are displayed on the screen in a polygonal pattern. The method permits a set of relatively imprecise user motions to be translated into the equivalent of a precise motion, thus allowing a disabled person to interact with a computer without having to use the familiar "hunt and peck" technique. When people are using this polygonal keyboard interface, their motions are suggestive of handwriting with a specialized alphabet. A sample code of motion vectors, an example of a specific user selection, and an octagonal vector keyboard are described.

INTRODUCTION

With the recent widespread availability of microcomputers, numerous interfaces have been developed for the disabled which augment or replace the standard keyboard.[1,2] This article relates to an important characteristic of keyboard usage that should be adressed whenever the underlying nature of the interface permits. Specifically, a touch-typist focuses attention on the characters as they appear on the screen, and does not watch his or her hands, or the keyboard. When fine motor control of the fingers and hands is not present, standard keyboards are often unable to permit this type of efficient use. A typing session for many disabled individuals consists of some variation of the "hunt and peck" process, in which a user repeatedly search a screen, keyboard, menu, or other device prior to making a selection. This paper describes a method with which disabled people can interact with a computer by using learned motion combinations in a manner similar to a typist.

DEFINITIONS

Input device: One of a variety of standard devices such as mouse, joystick, ultrasound head set, keypad, and others.

User motion: A single movement in one direction, made by the user, and indicated by means of an input device.

Motion vector: The abstract representation of a user motion.

Motion vector set: The combination of two or more motion vectors.

User selection: Any final, desired input objective such as a character, function key, macro, or other. Each specific user selection is defined by a motion vector set.

Code: A set of user selections, sufficient to implement a computer interface.

Vector keyboard: A dynamic, or changeable, representation of a keyboard that is displayed on a screen. This representation consists of user choices arranged in a polygon of n sides, with the neutral position located at the center of the polygon.

CODE OF MOTION VECTORS

The sample code illustrated below in Figure 1 shows sample mapping of user motion vectors onto the alphabet. Each selection requires two motions as shown by the joined vectors. The vectors represent the directions in which the user moves the joystick or other input device to complete a selection.

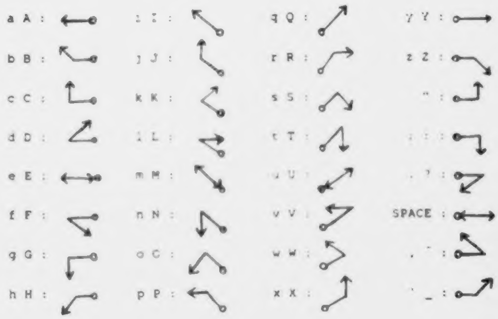

Figure 1

Figure 2 shows a sample code of motion vectors for various additional keys and other selections available to the user.

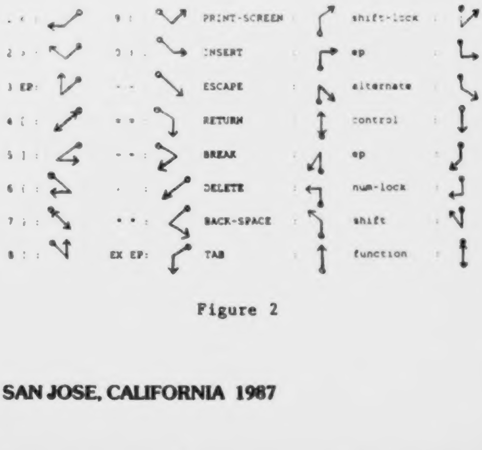

Figure 2

EXAMPLE OF A CHARACTER SELECTION

The term "vector keyboard" refers to the representation of user choices in a polygonal pattern on a monitor, as shown below. A user motion directed toward one of the sides of the polygon will cause a change of state to the next set of user choices. This motion can be relatively imprecise, and when an appropriate motion vector set is completed in this manner, a user selection results.

The polygon in the vector keyboard can be an octagon, hexagon, or square, although polygons of more or fewer sides can be used depending on the motor control, or preference, of the user. For example, there are advantages to using the dodecagon or decagon, if user control permits. In this example and in the remainder of the description, an octagon will be used. The pattern in Figure 3 shows the appearance of the keyboard at the highest level.

keys

ijklmnop qrstuvwx

abcdefgh _ yz:;'.,"

extra/*12345 =-+67890

modes

Figure 3

As an example, assume that the user wishes to type the letter k. By making a joystick motion up and to the left when the keyboard is as shown in Figure 3, the user will cause the vector keyboard to change state, and the following eight selections will appear:

j

i k

p _ l

o m

n

Figure 4

Now, a motion up and to the right will select the letter k. Therefore the representation of k, as joined vectors, is as shown in Figure 1.

After the letter k has been selected, the vector keyboard returns to its initial pattern, Figure 3.

A VECTOR KEYBOARD

It can be seen from the above example that selecting any of the eight choices in Figure 1 will cause a new polygon to be displayed with eight further choices. In addition, new sets of polygons are displayed when the user is in SHIFT, SHIFT-LOCK, CONTROL, and other modes. Therefore, the implementation of a vector keyboard involves mapping all keyboard functions onto a code of motion vectors, thereby defining the complete set of polygons and their interrelationships.

These polygonal configurations can be expanded by adding additional levels according to user preference. For example, polygons containing high level functions can be inserted at any position desired. This flexibility permits unlimited customization for individual requirements.

IMPLEMENTATION

This section describes the approach taken by the authors for the actual implementation of the above described motion-vector code. A program was developed using an IBM PC, a mouse, and the Turbo Pascal programming language.

The program consists of three modules: a mouse interface, a motion-vector translator, and a word processor. The function of the mouse interface is to repeatedly check for user motions, and convert the motions into values representing the current position of the mouse. These values are used by the motion-vector translator to generate the specific character represented by the sequence of user motions. These characters are then sent to the word processor, where they appear exactly the same as if they had been typed in using a keyboard. These characters constitute commands as well as text input, so that all features of the word processor operate in the usual manner.

As can be seen, the above described program is an interface to a single piece of software, a word processor. However, the method can also be used to provide a general purpose computer interface. Implementation could best be achieved by installing the program as a low level device driver, which would in effect incorporate the method as an extension of the operating system. Implementation at this low level would provide a transparent interface to all higher level programs, and would permit the use of a wide selection of standard commercial software. A vector keyboard interface to MicroSoft Windows (TM), for example, would provide an excellent computing environment.

Since the vector keyboard depends on a discrete set of use motions, the joystick guide was developed. This is a thin plate attached to the top of the joystick to help channel user motions in the desired directions. Its shape is shown in Figure 5. In the neutral position, the joystick shaft extends through its center.

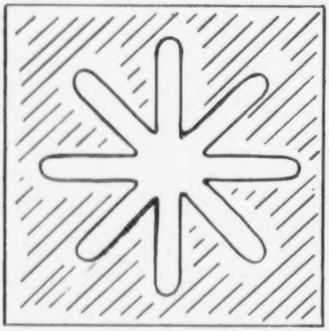

Figure 5

Finally, there are many possibilities for configuring a polygonal vector keyboard. Figure 6, for example, shows a ten-sided pattern. Two advantages of this pattern are that SHIFT and RETURN can be represented at the highest level, and all digits can be displayed in a single polygon.

```
              [ ( { <  > } ) ]

     abcdefghi            1234567890

 klmnopqrst                  Special Keys

 uvwxyz/-+*                  SpTbBk_:;.,!?

          SHIFT            RETURN

                Ext "%&\|#^~=
```

Figure 6

CONCLUSION

A method for a human-to-computer interface, based upon a code of vectors related to user motion, is described. The method uses a screen-displayed vector keyboard in which user choices are arranged in a polygonal pattern, and in which the neutral position is the center of the polygon. A motion to any particular side of the polygon will define one vector, which is then used in combination with other vectors to define a user selection. The association between a specific motion sequence and a specific character is easily learned, and can permit a disabled individual to interact with a computer without having to scan menus or keyboards. When a skilled person is using the vector keyboard interface, their motions are suggestive of handwriting with a specialized alphabet. Various input devices can be used, including joystick, mouse, and ultra-sound head set.

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The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the U.S. Government.

A DC INPUT MOUSE EMULATOR

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ABSTRACT

The popularity of the mouse as a convenient input device for personal computers has given rise to a vast array of mouse controlled software. The overall ease of operation and reduced input demand of these programs suggest their use by the disabled. Unfortunately, many people lack the physical ability to operate a mouse. Presented in this paper, is an interface adapter that converts a DC signal into the quadrature phased pulse output of a mouse. With the aid of this interface, sensors such as switches joysticks and inclinometers can be substituted for the mouse.

MOUSE OUTPUT

The directional output of a mouse like the one supplied by Apple for it's Mcintosh and Apple computers is a fairly complicated series of overlapping pulse trains. These signals, when decoded, tell the computer how far and in which direction to move the cursor. Separate sets of outputs control horizontal and vertical movement. Another output which is used to pull down menus and make selections is much simpler, consisting of a normally open switch to ground. Figure 1 illustrates how the direction of cursor movement along the horizontal axis is controlled by the phase of one pair of outputs. This is sometimes referred to as a quadrature output since the waveforms are always 90° out of phase. In the mouse these pulses are produced electro-mechanically by an optical switch and a slotted encoder disc that spins as the mouse is moved.

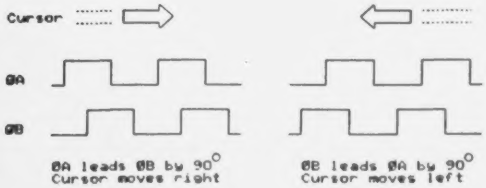

Figure 1

A circuit for electronically producing quadrature waves is shown in figure 2. U1A is a simple pulse generator whose output frequency can be varied over a wide range by adjusting potentiometer R1. This adjustment determines how fast the cursor will move. The output of the pulse generator is fed to a digital phase shifter made up of flip flops U2A and U2B. The flip flops divide and separate the signal into a pair of 90° phase shifted square waves that will maintain quadrature regardless of input frequency.

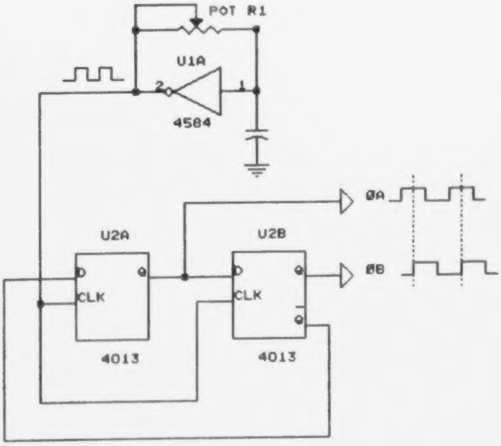

Figure 2

The circuit in Figure 2 will get the cursor moving, however, to reverse directions, the phase of the output signals must be reversed. Figure 3 illustrates how a 4066 quad bilateral switch can be used to accomplish this task. The 4066 also provides a convenient means for gating the signals. The control inputs of switches SW1-SW4 are tied together in pairs, enabling them to function as double pole single throw switches. Pull down resistors R2 and R3 keep the switches turned off until one of the pushbuttons is actuated. The phase reversal is accomplished by crossing the signal input lines to one set of switches. Pressing the UP button, for instance, closes switches SW1 and SW2, routing ØA to Output A and ØB to Output B. Selecting DOWN, on the other hand, closes switches SW3 and SW4, sending ØA to Output B and ØB to Output A. For normal operation, only one pushbutton should be operated at a time. However, in the event that both buttons are pressed at once, resistors R4 and R5 protect the circuit from damage.

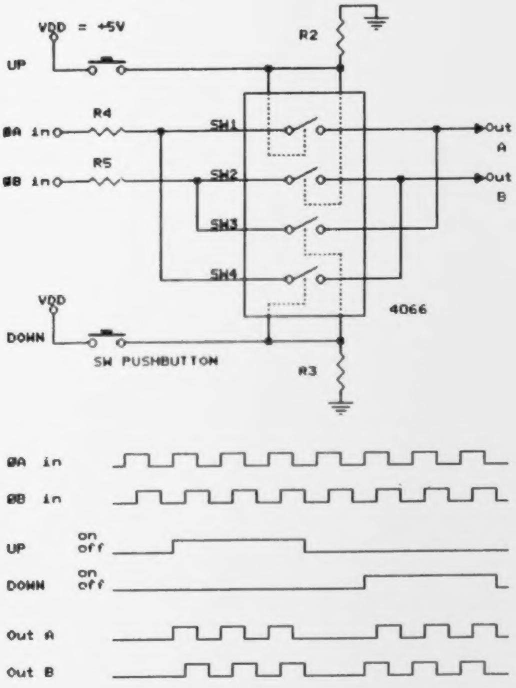

Figure 3

PUTTING IT ALL TOGETHER

Figure 4 is a detailed schematic of a functional switch-controlled mouse emulator. Separate 4066's are required to control the horizontal and vertical axes, however, a single pulse generator and quadrature convertor can be shared by both. Inverters (U1A,D,C,F) on the outputs are used as buffers to insure adequate power to drive the computer's electronics. The control switches (pushbuttons) do not have to be mounted in close proximity to the rest of the circuit. Connector P1 is a 9 pin male sub-D connector that matches the mouse port on the Apple and Macintosh computers. Power for the interface is supplied by the computer, eliminating the need for batteries or an external power supply.

DISCUSSION

Switches were selected as the input devices for this interface because of their simplicity and versatility. They are available in diverse configurations, many of which lend themselves to operation by the handicapped. Some integrating controls such as digital joysticks are switch based and easy to modify. A game joystick can provide an inexpensive alternative to the mouse for someone who does not have the range of motion or the coordination to operate the mouse. Individuals who use a joystick to steer their power wheelchairs should adapt well to this type of input. Tilt switches and sip and puff switches are other devices which may be considered where hands free control is required.

ACKNOWLEDGEMENTS

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MOUSE EMULATOR

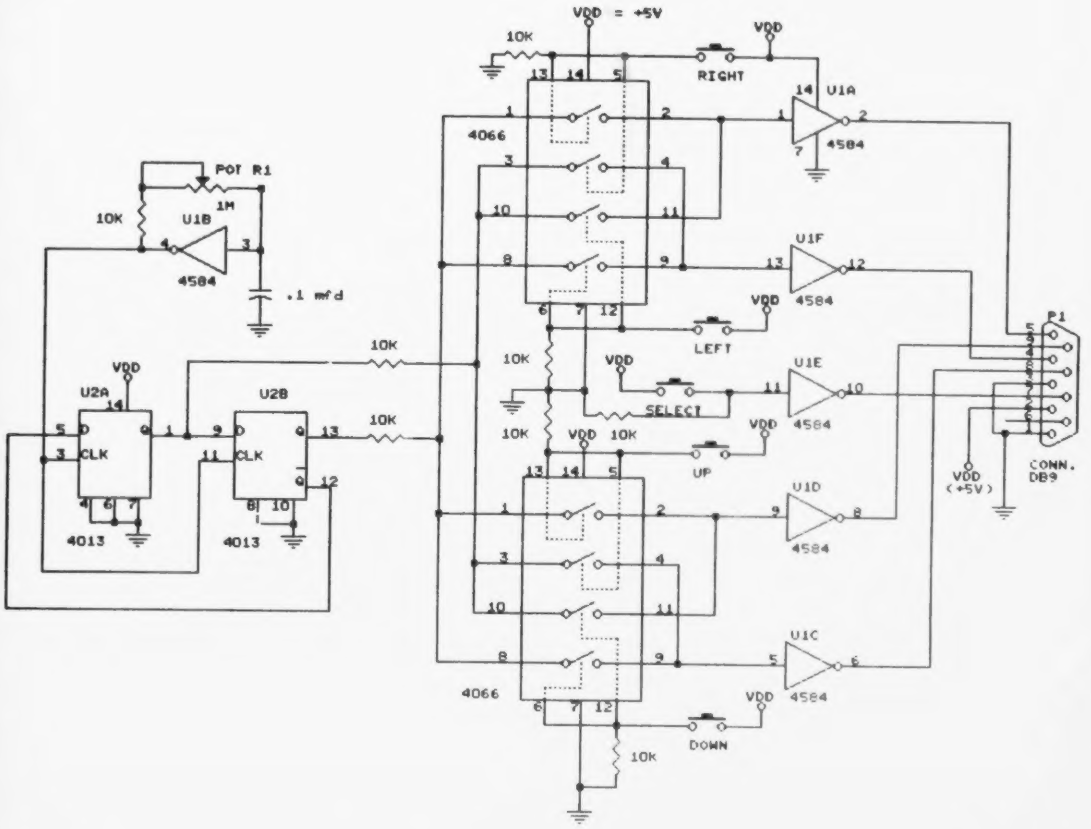
VDD = +5V
10K
VDD
RIGHT
13
14
5
1
2
4066
3
4
10
11
8
9
6
7
12
U1A
4584
U1F
13
12
U1E
11
10
U1D
9
8
U1C
5
6
LEFT
SELECT
UP
DOWN
POT R1
1M
10K
U1B
4
3
4584
.1 mfd
U2A
U2B
D
CLK
Q
4013
4013
P1
CONN.
DB9
VDD
(+5V)

Figure 4

PROTOTYPE DEVELOPMENT OF A SYSTEM PROVIDING FOR INITIAL ASSESSMENT OF THE DYNAMICS/KINEMATICS OF BIPEDAL MOTION

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ABSTRACT

A simple, yet highly adaptive system was developed providing for the dynamic analysis of bipedal motion. The computer integrated system allows for real time data capture, high speed sampling rates, and a portability that frees the user from laboratory confining electronics. A clinician, with minimal instruction, can proceed with data sampling and analysis without assistance or adversely affecting experimental integrity. The system consists of a triaxial accelerometer, signal amplifiers for each output, a power supply, and a microcomputer configured for direct data acquisition. The amplifiers and accelerometer are worn by the subject. During initial development, the accelerometer was located at the lower lumbar region in close external proximity to the subject's center of gravity with the axes sensitive to movement in the vertical, antero-posterior, and medio-lateral directions. Cabling connects the amplifier outputs with the remainder of the system on the benchtop or cart and software allows for user friendly control all aspects of data capture and plotting. While data from preliminary tests compares favorably with expected results, controlled laboratory runs and detailed analyses are pending.

INTRODUCTION

There are numerous alternatives to motion analysis available in today's marketplace. High technology provides the complex systems needed to define the dynamics and kinematics of motion. Such systems allow biomedical and rehabilitation engineers and technologists to collect and analyze motion data in the laboratory. What, however, of the clinician or researcher who has limited engineering and computer skills yet desires an interactive method of analyzing bipedal motion? Moreover, can such a user friendly system be untethered from the confines of the usual motion analysis laboratory without compromising data integrity in light of portability?

The purpose of this project seeks to address these issues and more. The preliminary results discussed here utilize a triaxial accelerometer, its associated peripherals (i.e. channel output amplifiers and power supply), and a microcomputer configured for data acquisition. The end product is a first generation computer integrated prototype of a simply operated and portable system adaptable to measurement of any number of motion parameters.

RESULTS

The assembled system is elegant in its simplicity, yet it still accommodates the complexity of human bipedalism. The computerized module maintains a user friendliness that would appeal to even those with moderate computer and experimental skills. Once attached, the technician merely responds to software generated commands that control all aspects of data sampling and plotting.

The motion system consists of four primary components: an Entran triaxial accelerometer, its associated signal amplifiers, the power supply, and an IBM PC/XT microcomputer. The former two are worn by the subject in a belt/backpack combination, while the latter two are located on a benchtop or cart. Figure 1 provides a simple schematic of the system.

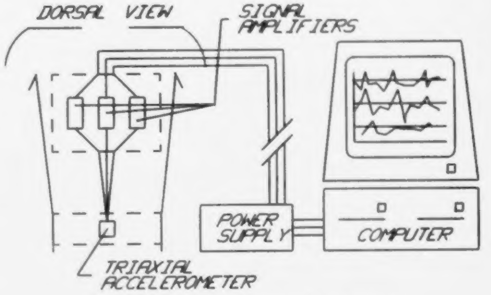

Figure 1. Motion system schematic

Now let's examine the aforementioned individual components in more detail. The accelerometer is attached to a belt worn around the waist and locating it posteriorly at the upper portion of the sacrum or lower lumbar region of the subject. Figure 2 illustrates the prototype units as they are worn by the subject.

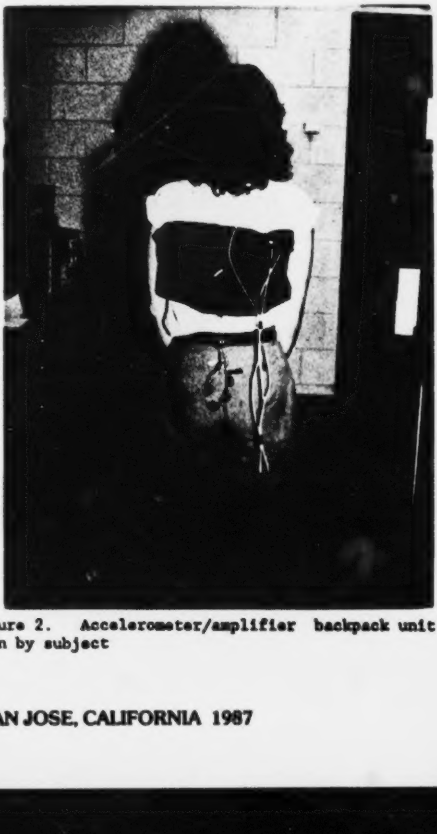

Figure 2. Accelerometer/amplifier backpack unit as worn by subject

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[a] This work was begun while the author was a student at The Georgia Institute of technology.

The power supply serves to power the accelerometer, provide a common ground for the system, and link the accelerometer outputs to the computer. The computer is the central unit of the entire system. It initiates and controls data capture, creates easily accessible data files, and plots the results of an experimental data capture session. A Tecmar analog to digital circuit board installed in the computer provides the interface between the analog output voltages of the accelerometer and the digital signal required by the computer.

The next aspects of the system to be discussed are the data sampling and plotting software routines. Once the programs have been booted up on the computer, the user is prompted as to what information is needed or which aspect of data capture or plotting he/she is to proceed with next. Figure 3 is a representation of a typical data plot output from the computer. The three traces are the accelerometric components in the medio-lateral, antero-posterior, and vertical directions, respectively, from top to bottom. The mantissa of each trace is a function of the raw data received from the accelerometer.

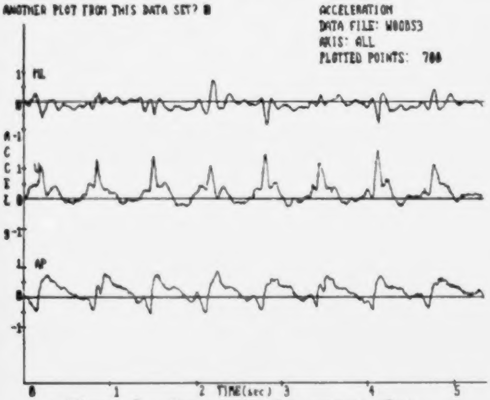


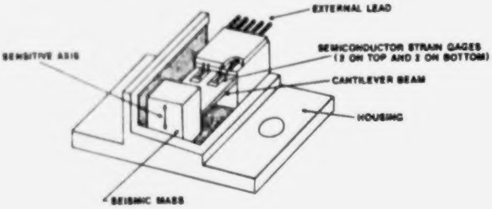
Figure 3. Representative output plot

DISCUSSION

System development begins with a plan. The impetus for this project comes from the need for a simple, highly adaptive, yet portable system that provides the user/clinician/technician with an accuracy of data capture within the confines of experimental protocol. Such a system must also provide for the maintenance of data integrity.

The vision of human bipedalism is deceptively simple. The dynamics and kinematics, on the other hand, are infinitely complex. The problem now evolved is how to reduce this paradox in the development of an effective diagnostic tool. How can we devise a system that reduces or redefines the body's movement about the primary body axes? First, we must determine what these axes are. Typical biomechanics define them as vertical, antero-posterior (front to back), and medio-lateral (side to side). The measurement of this motion is accomplished through the use of a triaxial accelerometer. Next, somehow we must define the placement of the accelerometer. For prototype development, the transducer was located at the upper portion of the sacrum or lower lumbar region on the dorsal or back side of the subject. Thirdly, can we integrate the system with a computer providing a fast and accurate sampling rate, meaningful graphics, and operator ease without destroying protocol or sacrificing data integrity? Can such a computer dependent system be portable enough so as to remove the tether to the sometimes data altering sterility of the traditional motion lab? A personal computer with enhanced memory and graphics capabilities addresses these concerns quite nicely.

The accelerometer, specifically for this case, the triaxial accelerometer, is a transducer whose outputs provide analog signals relative to accelerations along a specified axis. Motion in all directions can be defined through the use of a triaxial accelerometer whose axes are orthogonal. The Entran triaxial accelerometer generates an output signal through the oscillation of a semiconductor strain gaged cantilever beam (See Figure 4). As the massed beam vibrates in response to motion, the resistance of the semiconductive material changes and the resultant output signal is calibrated to the magnitude of the vibration. There are three such strain gage set-ups in the triaxial accelerometer, with each being sensitive to a different axis.



© Entran's EGC-240 Accelerometer Cutaway

Figure 4. Cutaway of a single axis accelerometer

Next, for the computer to be receptive to the input of raw data, it must be equipped with the necessary hardware enabling this function. An analog to digital converter accomplishes this task. The A/D converter is a circuit board installed directly into the computer's mother board. Once in place, the user can specify through software commands any number of parameters to control data acquisition. The A/D board eliminates the user from the data sampling loop, greatly increasing sampling rates while reducing experimental error. The data received by the board is channelled directly to the computer's memory. In addition to increasing and controlling sampling rates, software commands can specify exact memory locations and can sample several incoming data channels simultaneously. A computer so equipped is critical to the portability and efficiency of the motion system discussed here.

Finally, some assessment must be made as to the location of the accelerometer on the subject. As with any body in motion, the most stable point is the center of gravity. The motion of this is most indicative of total body movement. In humans, the center of gravity is somewhere near the obvious location in the low to mid torso. Previous anthropometric studies have established it as being near the upper sacrum or lower lumbar region and more dorsally than ventrally. Thus the decision to locate the accelerometer near this region becomes apparent. Ideally, the device should experience as little extraneous movement as possible. In other words, the accelerometer should detect motion of the subject only and not of motion of the belt or loose fitting clothing.

CONCLUSION

The motion analysis system discussed here offers several enticing conclusions. The computer integrated system allows for real time data capture, high speed sampling rates, and data plotting. Perhaps the most intriguing aspects of the system are its portability and user friendliness. Portability, which was one of the desired design features, is advantageous because it severs the ties to the traditional, allowing the user to take the system out into the field and into real world settings. Furthermore, the often intimidating surroundings of the medical laboratory will cease to be a factor in subject discomfort if the tests are run in the more familiar surroundings of home, hospital room, or physician's office. The user friendliness of the system is attractive because it allows even the novice computer operator to run a test with only minimal instruction. More importantly, such data capture can take place without adversely affecting experimental protocol or integrity. Yet another feature of the system is its adaptability. The accelerometer can be relocated so as to quantify any number of parameters such as upper body rotation or limb movement, both normal and pathologic, under the visage of motion analysis. Modifying the system to measure these quantities would involve, primarily, the reconfiguration of the accelerometer mount. Little or no modification of the software routines would be necessary.

The system discussed here is designed to provide a simple yet effective means of quantitatively analyzing human bipedal motion. Any one of a number of modifications can be effected to enhance the capabilities of the system providing additional experimental data or adding more substance to the existing data. The prototype system in its current state is very basic and provides data at this level. The simplicity of its design thus makes it receptive to further expansion. As an example of a possible venue for this expansion, a telemetry system might be integrated into the backpack unit to send data directly to the computer while eliminating the cabling that might interfere with the subjects normal movement. A second modification might be the addition of a triaxial gyroscope to fix the axes of the accelerometer during data capture. Human bipedalism is a complex activity, yet the system described here provides data that is useful in making preliminary analyses of the dynamics and kinematics of movement.

ACKNOWLEDGMENTS

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MOTIGAME

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ABSTRACT

The modification of a hand held computer game and its use as a motivational aid by the occupational therapist to encourage activity participation and to develop muscle strength in children is described. The computer game is modified so that the speed of the game can be varied and its activating paddles are extended. These paddles are used as limit switches to define the type of and to limit the range of exercise therapy used. The clinical problem experienced by the occupational therapist is introduced, the Motigame as a possible solution is presented, advantages and disadvantages of its use, an application approach and finally the conclusion is presented here. It has proven to encourage intellectual development and to motivate functional movement to any patient's benefit.

INTRODUCTION

The occupational therapist in a paediatric hospital is often faced with children who have very little or no functional movement. This is due to many crippling pathologies, for example, Guillain Barre Syndrome.

A child suffering from Guillain Barre lies for weeks on his/her back and may be attached to noisy life supporting machines. They are usually frustrated and frightened by their lack of movement and often can only stick out their tongue, nod their head or open and close their eyes. Selecting and applying appropriate activities for such a child is a problem.

THE MOTIGAME

A small, compact game was used to aid the occupational therapist in overcoming this problem. The game is easy to set up in the intensive care unit, easy to play, relatively noise free and can be operated with very little movement anywhere on the body and with very little muscle strength.

The game, called the Motigame, is a small hand held computer game, light and compact which can easily be set up. It is battery operated and does not interfere with any equipment in the intensive care unit. The computer game is modified so that the speed of the game can be varied from very slow to fast. This is achieved by replacing the fixed oscillator of the game which determines the game speed with one that is variable. The normal activating paddles (switches) are extended to form limit switches to regulate the range and type of exercise. The microswitch used operates when its actuator is deflected in any direction. Custom made brackets need to be manufactured to hold these switches at the various parts of the body. A game with two activating switches is chosen to simplify the exercise while a game with more switches can be used for complex exercise formations.

ADVANTAGES OF THE MOTIGAME

The game has a colouful picture which encourages curiosity and fantasy. The two microswitches which change the colourful picture, encourage present movement in the body and builds up muscle strength of the movement. It motivates the child to achieve a goal and is rewarded with points when the goal is achieved. It can be competitive if used in a group. Concentration and quick decision making is encouraged, something children often lose when hospitalised for long periods. On a perceptual level it helps the child to develop laterality and spatial relationships. It provides good visual stimulation and encourage visual tracking and coordination. It promotes dexterity of the movable part, be it the tongue or the two index fingers.

The game is gradable. As more movement returns so it can be put to use to play the game. Grading such as movement with gravity then movement against gravity; movement through a few degrees of range to movement in full range; and movement without resistance to movement with resistance is very useful to encourage improvement. The length of the session is gradable thus encouraging more concentration.

DISADVANTAGES OF THE MOTIGAME

The game could be disruptive in a therapeutic interpersonal relationship. This can however be prevented by including the therapist in the game eg. to write down the score or operate one switch on the patients command. One should guard against unwanted competition between patient and therapist. The game can also lead to anti-social withdrawal and should not be used when the patient has opportunity to socialise.

If there is little variety in the game the child can often become bored. Here it is important to keep the session short and fun, to provide different types of motigames and to use grading so that the child is working towards a long term goal as well.

Sometimes the child gets over-excited which can lead to fatigue. The child could also get headaches if the game is too close to his eyes or played for too long. If the child gets frustrated due to repetitive failure retrograding must be done to a level of the child's achievement.

APPLICATION

The motigame initially appeared to be yet another piece of unfamiliar equipment that could be threatening. This could compound the therapist's problems in dealing with the child. The therapist does not want the child to fail at anything because the child's level of achievement is usually limited.

One approach is to first start the child on a battery-operated toy eg. a car which has a microswitch attached to it. In this way the child becomes familiarised with the concept of a toy being operated by his head movements instead of his hands - not an everyday concept for any child.

Once the child can successfully operate the toy car and the microswitch, the motigame can be introduced and with success, provided the child has sight, some controlled movement and understanding of the game. The game would first be explained and then demonstrated and repeated until the child has full understanding. Needless to say that it is a good way of picking up some perceptual problems.

CONCLUSION

The motigame, a simple, compact computer game operated with microswitches is very useful with patients who have very little movement. It can also be used to encourage a patient who is frightened to move a limb, for example due to a burn. By grading the demanded movements, muscle strength and range of movement can be improved. It can thus be an intellectual or adventurous exercise to any patient's benefit.

ACKNOWLEDGEMENTS

The computer games were bought by the Friends of the Children's Hospital, Red Cross Children's War Memorial Hospital.

This project was initiated by Dr T. Hughes who modified the first computer game.

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COST EFFECTIVE GRAPHICS FOR REAL TIME DRIVING SIMULATION

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ABSTRACT

Simulation of the driving tasks can be a safe and easily controlled method of assessing and training potential drivers of personal licensed vehicles. But the lack of a cost effective programmable video display has slowed the use of simulators by a majority of potential drivers. Consequently, a microcomputer based driving simulator display has been developed that displays a programmable perspective image of the driver's view of a skyline with a two lane roadway in real time (15Hz). Capability for displaying additional objects, sound, display text/numbers on the screen, and read/write data to the display computer's RAM have been included. This assembly language software package is controlled through its user part which receives commands from the vehicle math model computer. The command structure is efficient and this allows the C64 to provide a cost effective video display for driving simulators.

INTRODUCTION

A simulator is a training device which resembles the equipment to be used in the final performance (1). Driving simulators provide a similarity at the man-machine interface but without the possibly harmful consequences of the man-machine-environment interaction. Thus simulation of the driving task is seen as a safe and controlled method for assessing and training potential drivers of personal licensed vehicles. The need for simulators becomes even more apparent if the potential driver has suffered some accident which leaves him disabled in one form or another. Large sums of money have been spent in flight simulators (2) and driving simulators (3), but the question still remains as to whether realistic driving conditions can be simulated at a price which facilitates the spread of technology. Cost containment has recently been accomplished by assuming certain aspects of the task are not essential to the assessment or training. Some commercial driving simulators have opened the loop between the control surface inputs and the view of the roadway, choosing to assess initial control surface activation in response to various visual cues (4).

But the current proliferation of the microprocessor based computers with enhanced video graphics and sound integrated circuits suggest the possibility of reintroducing the closed loop aspect of driving simulation by generating a medium resolution video image of the roadway in response to a digital simulation of vehicle dynamics using the control surface positions as forcing functions. As this effort is for application to disabled drivers, "zero-effort" steering is assumed. Reported here are an overall design approach and details of the video graphics display.

METHODS

System concept

Distributed processing separates the video graphics task from the vehicle dynamics simulation, figure 1. A large video image is generated by the first computer whose display software is "booted" from non-volatile memory (EPROM). This computer receives appropriate display commands from the vehicle math model computer over a parallel bus similar to a computer-printer link. The vehicle math model computer receives inputs from an A/D converter that digitizes the analog signals from the steering, throttle, and brake controls. A disk drive stores client information and simulation results. Additional files on the disk are routed to the graphics computer that relate details of the monitor-cockpit geometry.

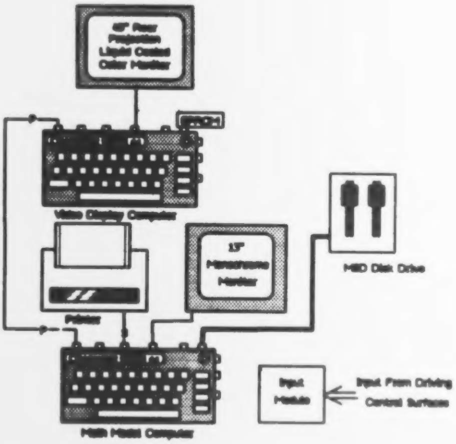

Figure 1. Distributed Simulation System.

Sky and skyline

The top 5 character lines have their background color set to sky blue, the skyline/cloud area being the four rows of the top 15. Each 40 character row is a window from a 256 byte array. Rough scrolling of the skyline is accomplished by choosing a 40 byte window from the 256 byte block while smooth scrolling makes use of horizontal scroll control in the video chip.

Roadway

The grass/roadway area is generated by a refinement of an idea first used by the General Motor Research Laboratory (3) in that a perspective view of the roadway was generated by a series of bars located one above the other whose length reflected the road width in perspective. Curves were simulated by adjusting the lateral position of each bar as appropriate. We update their 5 bar oscilloscope display with 64 video scan lines with green grass and a grey roadway using bit mapped graphics. Computing time was conserved by presimulation computation of each scan line in multiple versions with the appropriate version (lateral position) selected during run time and moved as a block from RAM to the video display area. The width of the road in each scan line is determined from a road width table which is loaded into the display computer from the math model computer during initialization. The center of the road bar is determined by 9 bytes, each specifying a lateral coordinate for every eighth scan line. The lateral position of the intervening scan lines are interpolated. The required 9 bytes are sent to the display computer during simulation.

Center line

A broken white, fading to gray, center line is superimposed on the grass/road image by masking bits during the block move. The bits masked are selected from a centerline table of which there are many versions, each differing from each other by the distance from the viewer to the start of the white area. The perception of forward motion is accomplished by sequentially selecting center line tables which reflect a change in distance appropriate for the vehicle speed and monitor-cockpit geometry. To enhance the sense of forward motion, yellow broken lines at the road edge appear to move by the same technique.

Road signs and traffic

Sprites, movable object blocks (5), can be superimposed anywhere on the screen. These blocks can be set up to be cars/trucks, signs, obstacles, and roadside posts. Manipulation of multiple sprites each locked to the roads edge or a single sprite relative to the center line simplifies sprite placement. Four bytes must be sent to position a single sprite and 2*(Ntl) bytes are needed to position N sprites along the road edge.

Sound

Advantage has been taken of the 6581 Sound Interface Device to product various sounds. These include motor, tire contact shoulder, tire contact centerline, crash, and windgust noise. Control of sound requires one byte.

Control

The display computer boots itself from EPROM and waits to receive commands from the vehicle math model computer. A road width table (64 bytes) and centerline descriptors (8 bytes each input) are sent from the math model computer and a command is sent to initialize the system. This process generates the multiple copies of the 64 scan lines and generates a program that facilitates the maskable block moves of these scan lines. The computer is then placed in the SYNC mode and ready to receive graphics commands. Commands and their required bytes are received by a 256 byte buffer. If the buffer is full a "not ready" signal appears on user part.

RESULTS

Table I is an abbreviated command list with execution time. The F9 command is the minimum picture drawing command. Only 15 bytes are needed to completely generate the visual display with motor sound and speedometer display. This command can be sent at 15.6 Hz which is adequate for presentation of a real time simulation. Sending more commands would add objects to the display. F5 is useful for placing posts along the road or a possibly multiple sprite traffic sign, while F4 would facilitate objects on the road or other vehicles. In all cases multiple sprites images must be generated, different only in size. The math model chooses the sprite size by computing or choosing Z based on real world distance. Figure 2 was generated by sending the F9 command and shows the capability for a gentle curve. Figure 3 was generated the same way but with different coordinates and center line pointer and illustrates a sharper curve in addition to a different perspective. These still pictures appear somewhat jagged due to the resolution of the image generation. When in motion, this has not been judged as detracting by any of the sixteen clients. Apparently with the centerline, road edges and skyline moving and with the pseudo random dots in the grass area these quantization effects are not detracting from the main task at hand, i.e., operating the vehicular control surfaces in an effort to keep the vehicle in the center of the right hand lane. We observed that the a broken centerline in the distance disappeared because the width was less than the minimum display pixel. It was judged more pleasing to display a minimum width in this instance.

Table I. Command Format and Timing List.

Command = Action - Execution Time

F9 X1...X9 CL SK M S:Draw Screen-64.1 ms

X1...X9	Coordinates of road center
CL	Center line pointer (2 bytes)
SK	Relative sky scroll
M	Motor sound pitch
S	Speedometer reading

F7 X: Sound Effects - 0.5 ms
Bit 7 = hitting center line
Bit 6 = hitting shoulder
Bit 5 = crash
Bit 4 = wind gust

F5 L H Y1 Z1 YZ Z2...: Put sprites on road edge - 1.6 to 20 ms
L = lowest sprite number
H = highest sprite number
Y = Y coordinate of sprite
Z = Sprite definition Pointer

F4 S Y Z:Display one Sprite by Y - 1.8 ms
S = Sprite number
O = X offset from center

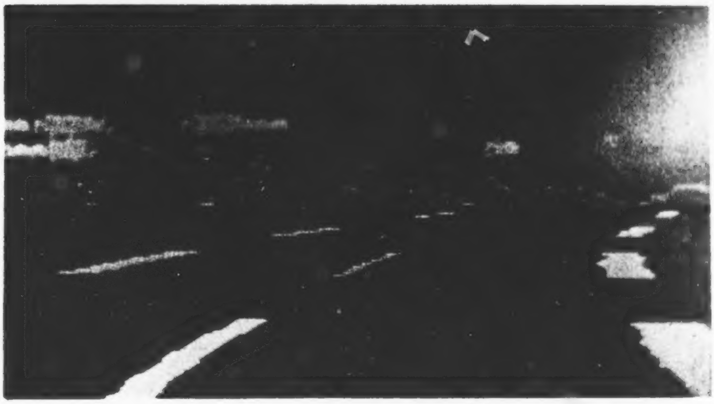

Figure 2. Graphics Display.

CONCLUSION

The development of a cost effective graphics display for real time driving simulation has been accomplished on a relatively inexpensive microcomputer ($$200) which runs in a turnkey mode from EPROM. Program execution speed was judged adequate. The image can be updated 16 times a second, providing a perception of a continually moving programmable roadway. The command structure is designed to require a minimum amount of data so that the overhead used for the distributed processing design is also minimal. This system shown in Figure 1 has been running for six months without major problems. Some enhancements have been made but no failure due to the graphics display program have occurred. Therefore the graphics computer-EPROM system is available as a stand alone system to be used as a component of a real time driving simulator.

ACKNOWLEDGEMENTS

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CASPER: COMPUTER ASSISTED SPEECH PERCEPTION EVALUATION AND TRAINING

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ABSTRACT

Speech perception is a complex process requiring the integration of sensory capacity, linguistic and world knowledge, and perceptual skills. Evaluation and training must take account of this complexity. Computer-assistance offers advantages in terms of control, adaptability, efficiency, and objectivity. This presentation deals with issues of speech material, storage media, and the design of audio- and video-interactive systems for speech presentation, response evaluation, and adaptive programming.

COMPUTERS IN EVALUATION

Speech perception is a complex process involving sensory, perceptual, linguistic, and cognitive factors. The evaluation of speech perception, whether for clinical or research purposes, calls for a variety of materials and procedures that permit evaluation of these factors, both separately and in combination. When a particular factor is to be investigated, it is crucial that the influence of other factors be controlled and that unwanted sources of variance be minimized. A first step in accomplishing these goals is the proper design of test materials and the selection of appropriate tasks. A second step is the recording of the materials. The use of computer-control for test administration can further assist by increasing objectivity and by permitting such things as randomized item selection, adaptive testing, and automatic scoring.

COMPUTERS IN TRAINING

To develop speech perception skills requires practice, i.e., time on task. The demands of everyday life often provide enough opportunity for practice, but sometimes the risks of failure seem too great and the individual concerned avoids communicative interactions. He or she is then deprived of the chance to learn. When this happens, there may be a place for formal speech perception training in a supportive, unthreatening environment. A computer-controlled system has great potential in such a situation. It can adapt to the subject's progress, it offers no threat of embarassment, it can provide automatic documentation of progress and of difficulties, and it may increase the amount of intervention that a single clinician can provide. In learning experiments, the use of computer control helps to remove unwanted factors such as experimenter bias and tester-testee interaction.

PURPOSE

The purpose of this presentation is to review the requirements of computer-interactive audio and video systems for speech perception testing and training, and to describe some ways in which those requirements may be met.

SPEECH MATERIALS

There is no single type of speech perception task that can meet every need. A range of tasks is required that place differing relative emphases on the various factors involved. For example:

a) Same/different or odd-man-out judgements
b) Nonsense syllable identification in a closed set
c) Word identification in a closed set
d) Phoneme recognition in nonsense syllables
e) Phoneme recognition in meaningful words
f) Word recognition in isolation
g) Word recognition in sentences providing differing amounts of syntactic, semantic, and topical redundancy
h) Tracking of connected discourse

Numerous materials are available that lend themselves to activities involving these various tasks. In our own work, we have used the THRIFT, a 3-interval, forced-choice task of speech pattern contrast perception <1>; the SPAC test, a multiple choice test that also evaluates the perception of speech pattern contrasts <2>; the AB short isophonemic word lists <3>; CUNY topic-related everyday sentence sets <4>; and commercially available story material.

STORAGE

If testing is to be restricted to the auditory modality, audio-tape recording is the obvious choice for storage and replay of speech materials. This is suitable for essentially linear programming. If rapid and accurate random access are required, advantage can now be taken of relatively inexpensive digital storage on hard disk, using a personal computer. For work with the visual modality (i.e., lipreading), video-tape recording can provide frame-accurate access and is again adequate for essentially linear programming. The video laser-disk, however, provides both frame accuracy and rapid access. It is the medium of choice for interactive-video systems. The mastering process for disks is complex and expensive, but copies can be produced inexpensively. As the medium becomes more popular, laser-disk recorded speech materials will become increasingly available from various research labs. Systems now exist that permit recording and replay of erasible laser disks, but the resulting disks are not compatible with the mastered variety. An even more powerful possibility is digital storage of video signals. This is now feasible, though at a cost that will prevent its general application for some time.

INTERACTIVE AUDIO SYSTEMS

Figure 1 illustrates an audio-interactive system that uses an Apple II computer and a Cyborg ISAAC general purpose interface. A custom-built interface permits control of the TEAC cassette deck transport via the remote control input. Tones on one track of the tape inform the computer about the beginnings and ends of test items. In the realization illustrated here, a separate response box is provided for 3-interval, forced-choice testing. In multiple choice testing, however, the computer monitor is used to show the response alternatives and the keyboard is used for subject response. A simpler implementation of this system employs a Tandy-Radio-Shack lap computer. The computer's cassette port is used to start and stop the TEAC deck and to detect control tones. When control of the fast-forward and rewind functions is required, this employs the computer's RS232 interface, but requires also a custom built interface for the tape deck. A more sophisticated approach to transport control and to the location of specific points on the tape employs a cassette player with a built-in RS232 interface. Such a machine is available from Tandberg.

INTERACTIVE VIDEO SYSTEMS

Figure 2 illustrates a video-interactive system that employs a video cassette player. Control of the transport functions, numbering of frames, and reading and location of frame numbers, is accomplished with a BCD Associates VCR controller, in this case employing an RS232 communications port. To mix the video signal with computer-generated text requires an additional unit. We use the PC-Keyer from Video Associates Laboratories. We have conducted several studies with this system, but the access time required by the transport mechanism has always been a source of annoyance. We are currently transferring to a laser disk system. This is not only faster and more versatile, it is also easier to program and less expensive. The hidden cost, as indicated earlier, is that of video-disk mastering.

One of the problems with computer-controlled speech perception and training systems is the input of open-set subject responses. Automatic recognition is not yet feasible, and

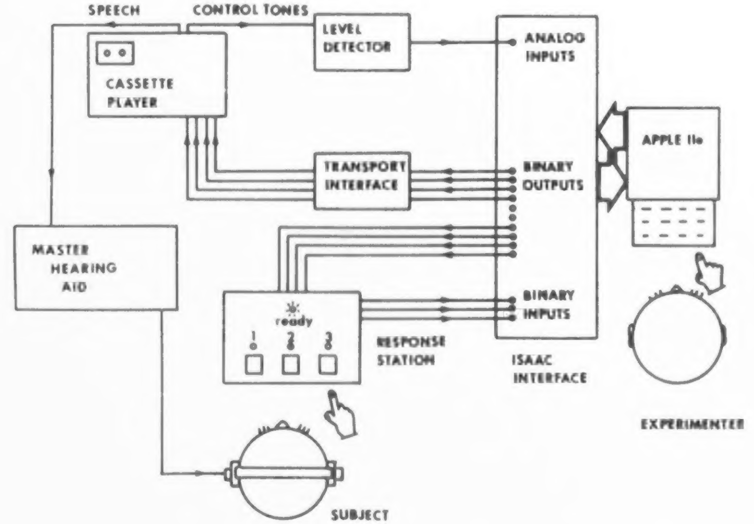

Figure 1. An example of a computer-controlled, audio-interactive cassette tape system.

keyboard input requires typing skills that are beyond many experimental and clinical subjects. Our solution has been to compromise the automaticity. It will be seen from Figure 2 that an experimenter interacts with the system through the computer monitor and keyboard. This permits the subject to give spoken responses which are entered to the computer by a number code. With this arrangement, we have been able to automate a variation of connected discourse tracking.

SAMPLE APPLICATIONS

The systems just described have been used by us for investigations of compression amplification in prelingually deaf children, rehabiliation of cochlear implantees, a wearable multi-channel tactile display of fundamental frequency, and the acquisition of lipreading skills.

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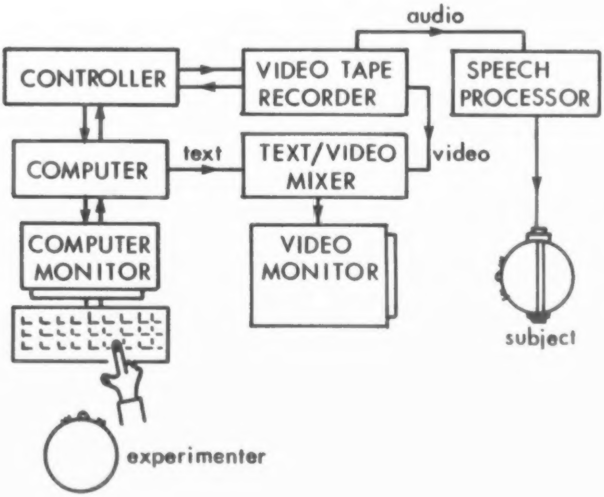

Figure 2. An example of a computer-controlled, video-interactive tape system.

A Progression from Simple Encoding to Morse Code

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Abstract: Several input systems exist whereby disabled children can have independent (or semi-independent) access to technical devices such as computers and communication aids. In terms of 'input rate' indirect access techniques such as scanning and encoding are the slowest and should not be recommended if there is a quicker alternative. This paper presents case histories of three athetoid cerebral palsied children who had no effective input option other than through contact with head-switches. These histories illustrate the progression of skills necessary to master 'encoding' as an efficient method of access to microcomputers.

Children and adults are using technical devices to enhance their independence in areas of mobility, communication, environmental control, education and recreation. Input rate, or the speed at which a disabled person can control his/her selected electronic device, is the crucial factor in determining whether that device will be of functional use to the individual. Neither power wheelchairs, nor electronic communication devices, nor microcomputers will be of any service if their operation is so slow that they become impractical or too frustrating to bother with. This article however focuses upon input to microcomputers only.

There are several methods by which disabled children can learn to control microcomputers. These include keyguards, expanded keyboards and mini keyboards (TASH Inc.), headpointing techniques that involve infrared technology (Computer Entry Terminal, Prentke Romich Co.), headpointing involving ultrasound (HeadMaster Workstation, Personics Co.), and keyboard emulators that allow for switch-control of software through a variety of scanning and encoding strategies (Adaptive Firmware Card, Adaptive Peripherals Inc.).

While relatively quick 'direct' methods of access to microcomputers can be mastered by many children there are others who, due to their physical disability, must learn to operate software through 'indirect' means. Traditionally it is the athetoid cerebral palsied child who is the most difficult to interface to technology and who ends up having to rely upon switch input.

When switches must be the source of a child's control of software there are, as previously mentioned, two principal input strategies; scanning and encoding. Of the two, encoding is the most efficient and can be applied through either one or more switches. Switches come in a wide assortment of shapes and sizes. Some switches operate as a result of touch (capacitance switches), others may require movement (mercury switches) or pressure (treadle, pad and plate switches). E.M.G. switches and very sensitive pressure switches (P Switch, Prentke Romich Co.) can be activated by very fine muscle flexion and can be readily mounted in suitable locations (i.e., forehead).

While there are several different types of switches we have had success with just a few. Most switches are either too small to contact by children with athetoid involvement or too delicate to withstand the severe beating that athetoid children deliver to switches. The Lever Switch (Zygo Industries) is one with which we have had good success. In most instances we mount two switches; one on either side of the head (where they appear to tolerate considerable abuse).

Encoding is a strategy that relies upon 'tone' feedback. Sustained contact with either switch will cause tones to be generated by the keyboard emulator (through the microcomputer's speaker) at a predefined rate. The tones generated by the child's left or right switch differ in frequency but are usually referred to as 'dit' or 'dah'. These tones can be paired to alphanumeric characters needed to run software. While Morse code represents a very comprehensive encoding system intended to give its user access to the complete alphanumeric set there are also much simpler encoding systems that can be custom designed at a moments notice to suit specific software applications. Most software uses only a small selection of 'keys'. A maze for instance may use the keyboards' arrow-keys or the IJKM cluster. A child dependent upon using switch access may operate this same software through the following encoding format:

"dit" (left switch) - - - - - - left
"dah" (right switch) - - - - - right
"dit-dit" - - - - - - - - - - - - up
"dah-dah" - - - - - - - - - - - down

Mastery of encoding input to microcomputers is illustrated through the following three case histories.

Case 1: Jason

Jason is a seven year old boy who is integrated into a special class within a regular elementary school. Jason has color/letter and number recognition. He has a basic understanding of the ordinal and quantitative value of numbers and has many of the concepts identified with children at the kindergarten to grade one level.

Jason has had no experience with technical aids nor with the cause/effect relationship of switch manipulation. His initial experiences therefore have been with very simple 'switch training' software. Catch the Cow (California Avenue School) and Motor Training Games (Adaptive Peripherals Inc.) gave Jason a firm mastery of 'switch control'. MSIP (Hugh McMillan Centre) is another alternative but is primarily intended as an assessment tool.

The Minnesota Educational Computing Consortium (MECC) produces an excellent series of 'early learning' courseware geared towards children at the preschool to grade 2 level. First Letter Fun, Fun From A-Z, Phonics Prime Time: Initial Consonants, and Phonics Prime Time: Final Consonants are programs that require only the (Return) and the (Arrow) keys. These keys have been reassigned to Jason's two head switches so that contact with one switch has the effect of depressing the (Arrow) and contact with the second results in a carriage return. He therefore has complete independence over this software. Other programs used independently or semi-independently by Jason include Sticky Bear Opposites (Family Reader Software), Peanut Picture Puzzlers and Mr. & Mrs. Potatohead (Random House), Garfield (DLM) and What's Next (Strawberry Hill Software).

Billy

Billy is also in elementary school. Billy's math skills test at the grade five level. His language arts skills however are considerably weaker (grade 2 level). Billy, in the past, has had experience with single switch operated row/column scanning devices and software such as the Handicapped Typewriter and the Zygo 16. This experience however was not a success as scanning input proved to be laboriously slow and intolerant of mistakes due to accidental switch contact.

Billy was introduced to two-switch encoded input one year ago. At first this involved use of very simple encoding strategies to several of the programs now used by Jason. Billy's encoding skills were elaborated upon so that he could respond to software needing as many as four 'keys'. These included Surrounding Patterns (Strawberry Hill Software), Same/Different, Animal Hotel and Shutterbug Pictures (Learning Technologies). The four keys needed by this software are entered by Billy through the following encoding sequences: dit, dah, dit-dit, and dah-dah using a rate of '4' on the Adaptive Firmware Card.

Billy has since progressed to Morse Code so that he now has the ability to input all alphanumeric characters. Although his output is still relatively slow (2-3 words or 15 characters per minute) he is generating text independently using Magic Slate (Sunburst Software) and News Room (Springboard Software) and can therefore participate more actively in an educational program. Billy's Morse skills will soon also be used to operate his communication aid (Epson SpeechPak ACS).

Melinda

Melinda is now a teenager. She never had the patience to work well with 'slow' electronic devices and for many years depended upon a one-to-one aid. Melinda has had experience with the old Possom row/column typewriter, strip printers needing optical headpointing input, Tetrascans and a host of other devices. However, it wasn't until she was introduced to Morse code that she began to excel academically. Morse presented Melinda with a reliable method of input to software. It isn't as fast as optical headpointing but for Melinda it isn't as prone to errors. Melinda mastered Morse within a week and has used it exclusively with word processors. Her 'starting' set-up for Morse was at a rate of 3 on the Adaptive Firmware Card. She now manages a control setting of 7.

Melinda is now an honors student in grade nine. Highschool has presented problems in that she now needs to have portable equipment that can be moved from class to class. We hope to provide her with this through one of the full-screen IBM compatible laptray microcomputers. The PC Aid (DADA Inc.) is a keyboard emulator that functions exactly the same as the Adaptive Firmware Card but is one that will interface to the IBM. Melinda will therefore be able to operate the new equipment with the skills she already knows.

Resource List

1. Adaptive Firmware Card (Adaptive Peripherals)
2. P.C. Aid (DADA Inc.)
3. Computer Entry Terminal (Prentke Romich Co.)
4. Keyguards (Antoinette Designs, TASH, Prentke Romich Co.)
5. Lever Switches (Zygo Industries)
6. Catch the Cow (Jane Birch)
7. MSIP (Hugh McMillan Centre)

Adaptive Peripherals Inc., 4529 Bagley Avenue North, Seattle, WA, 98103

Antoinette Designs, 8620 Burns Drive, S.W., Olympia, WA, 98502

Design Aids for Disabled Adults (DADA), 1224 Dupont St., Unit 5, Toronto, Ontario, M6H 2A2

Jane Birch, California Avenue School, Vista, CA, 92083

Hugh McMillan Centre, 350 Rumsey Road, Toronto, Ontario, M4G 1R8

Prentke Romich Company, 1022 Heyl Road, Wooster, OH, 44691

Technical Aids & Systems for the Handicapped Inc. (TASH), 70 Gibson Drive, Unit 1, Markham, Ontario, L3R 2Z3

Unicorn Engineering Co., 6201 Harwood Avenue, Oakland, CA, 94618

Zygo Industries Inc., P.O. Box 1008, Portland, OR, 97207

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SELECTING ADAPTIVE INPUT DEVICES FOR PERSONAL COMPUTERS

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Thomas A. Krouskop, Baylor College of Medicine

ABSTRACT

This project's objective is to design an evaluation methodology which accounts for a range of motion as well as the amount of force the potential user can exert or is required to exert in order to activate an adaptive input device for a personal computer when the minimum amount of force along with acceptable speed, accuracy, resistance to fatigue and range of motion are optimized. An appropriate input device can be selected so that the device maximizes the users probability of successful operation while minimizing the undesirable side effects.

In this study only upper and lower extremity operation sites were considered. The motor assessment technique is intended to be a quick but thorough means of identifying limb movements which are the most coordinated, have adequate, active range of motion, strength and absence of pain. The user performs the movements in the position used to activate their computer. The occupational therapist observes the subject and directly intervenes when appropriate. Movements are given scores that are adjusted so that the lowest score indicates the highest potential for using a particular input device.

INTRODUCTION

With the availability of adaptive input devices which bypass keyboard input, computers have provided the physically challenged with a tool for communication, learning and vocation. There are several such devices on today's market for various communication systems and personal computers. The question arises of which device would be the most desirable for an individual. How does one go about determining what type of device or switch will match an individual's needs and skills? While the price of adaptive computer switches have decreased some since their initial introduction on the market approximately 5 years ago, purchasing just any device that appears to be a good selection may be a costly mistake. In their study of input modes and their application for handicapped people, Lawrence and Horne (1) found that prediction of which input mode would be the best for a subject is often not valid. In many public school settings, many selections are decided from trial and error and observation. Often the selected device does not work as well as the therapist anticipated it would, although its selection is not particularly inappropriate. The children often appear to exert more effort activating the device than the therapist prefers. The efforts they had to put forth often led to loss of proper body position, fatigue, distraction from the end result of the task and frustration.

METHODOLOGY

There are many things to consider when assessing an individual for the most workable input mode. Variables such as mental abilities, perceptual skills, vision, personal preference, to name a few, are important. A team approach is ideal for evaluation because of the varying areas to be addressed. Areas which occupational therapists can offer their expertise are those of positioning, motor assessment, energy conservation and work efficiency.

Variables addressed by studies found in the literature search included frequency of activation, speed, accuracy, repeatability, fatigue, reaction time, duration of activation, and trial time.(1,2) None of the studies investigated the amount of force required by the individual to activate an input switch. Work equals force times distance.(3) The less force required by an individual to activate a device, the less amount of work results; provided distance has not increased in the comparison. This project's objective is to design an evaluation protocol which considers the amount of force a person exerts or is required to exert to activate an adaptive computer input device. If the minimum amount of force, along with the most desirable results of assessment of the variables mentioned above, were identified, then an optimal input device could be selected for a person which provides the most potential for successful operation and promotes a minimum of undesirable associations.

The approach used in this study started with a survey of the state of the art. Areas which contributed some information were computers and the handicapped, biomedical technology, biomechanics, ergonomics, rehabilitation and mechanical engineering, medical instrumentation and kinesiology.

Next, methods were designed for 1) determining potential location sites to be assessed for the operation of devices, 2) calculating the force exerted at the operation site upon the gauge, 3) addressing the amount of extraneous limb movements associated with each test, and 4) ranking the site/device selections.

This project constrains it's assessment to limb movement only. Therefore, the assessment to determine potential operation sites address only upper and lower extremity mobility. This motor assessment is intended to be a quick, but thorough means of identifying limb movements which are the most coordinated, have adequate active range of motion and strength, and absence of pain. The subject is asked to perform these movements in the position which they would be in for activating their microprocessor. The occupational therapist observes the subject and directly intervenes when deemed appropriate. Applicable movements are given a score and those with the lowest score are considered to have the most potential for activating input devices.

Calculating the force applied by the subject on a device proved to be the most difficult task of the project due to the unfamiliarity of gauges for registering force. After reviewing material concerning methods of determining force, stress and displacement, the two methods which were preferred were a gauge using an elastic element, such as a spring, and a strain gauge.(4,5,6,7) Force could be determined with the spring gauge by using the formulas:
$F = KX$ (tensile)
$F = -KX$ (compressive)
$X = X_o - X_p$
Force(F) equals the spring constant(K) times the deformation(X) which is the original length(X_o) minus the pushed/pulled length(X_p). Force could also be calculated using a bonded strain gauge by using the formulas:
$\epsilon = \sigma/E$ therefore $\sigma = \epsilon E$
$\sigma = F/A$ therefore $F = \sigma A$
By measuring the amount of strain(ϵ) and knowing the modulus(E) of the materials used, stress(σ) can be calculated. Stress is then multiplied by the area(A) the force is applied to calculate the amount of force.

Some of the constraints of this study are: to keep measurements as simple as feasible, and to avoid a complex, awkward testing apparatus. A reliable gauge which is simple to handle, easy to use and portable is desired. A meter/digital display is preferred over chart recordings or graphs. The display would be designed to register and store up to 3 readings without having to be reset.

Testing involves the application of force to the gauge(s) at the selected operational sites in positions which simulate the actual input devices. The minimum force required to activate the devices on the market would be predetermined. subject would be asked to "activate" the gauge in the following patterns:
S: short force L: maintained force
SSS, LLL, SLS, LSL
Movement, coordination, rhythm and consistent application of force are recorded. While the subject is being tested, a movement detector records any associated movement elicited while activating the gauge. Again, these are simple, inexpensive cuffs which are mercury switches. It is important that the cuffs be positioned consistently throughout the evaluation; i.e., on the forearm and calf of the leg.

With the goals and objectives clear and the variables identified, the actual fabrication of the gauges and displays would be done with the assistance of a biomedical or rehabilitation engineer. Calculating the minimum amount of force to activate the actual input devices involves thorough analysis of where forces are applied, location of movements, and measurements of areas and lengths. These can be written in a chart form and used as a reference and guideline during the evaluation.

After the testing is completed results are correlated so that the most desirable combinations of operation site - motor coordination - minimum force - style of device - least amount of associated movements be ranked in order of most potential. This correlation of test results can be done immediately following the evaluation or at a later date.

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A Method for the Dissemination
# of Very Inexpensive Communication Systems

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ABSTRACT

A scanning communication aid based on the Tandy Model 102 has been developed and discussed previously. A method for disseminating this work is being used to allow consumers to obtain a system for very low cost. The system is being distributed as a do-it-yourself kit that contains scanning software, a single switch interface, and a comprehensive manual. This kit allows the user to put together a system from commercially available components in a variety of configurations. Advantages to this method of dissemination include low cost, system flexibility, and expandability. The major disadvantage is a relatively complex system set-up procedure. The method is currently being evaluated for its effectiveness through questionnaires that accompany the kit and a log that documents technical support requests.

INTRODUCTION

Traditionally, non-profit research centers have distributed their products by contracting with an equipment vendor who takes over the marketing, sales, and support of the product. However, this method of technology transfer does not succeed in bringing every deserving product to market, resulting in unused products and frustrated developers.

We have experienced this frustration with a scanning communication aid designed here in 1984. The system, called *BOCCA*, was developed by the REC and is based on the Tandy Model 100, a portable, battery-operated computer.(1) (The Model 100 has since been upgraded to the Model 102.) The goal of that project was to combine portable computers and "off the shelf" peripherals (e.g., speech synthesizers) to produce relatively inexpensive and flexible communication aids. At that time, several rehabilitation equipment vendors were contacted in an attempt to commercialize the BOCCA system. When these attempts failed, we decided that the quality of the system warranted a different approach. After significantly upgrading the software, we have developed a method for dissemination that is an alternative to more traditional technology transfer channels. This method can be used to distribute any software based system that uses commercially available hardware. Following a brief description of BOCCA itself, this paper describes this dissemination method and discusses the advantages and disadvantages of this approach.

THE *BOCCA* SYSTEM

Bocca software provides row-column scanning on the Model 102 (or the older Model 100) and supports a variety of portable printers and speech synthesizers. A single switch is connected to the bar code reader input of the Model 102 via a small interface box that was designed here. This interface box is simply an optoisolator that prevents signals from the switch from interfering with the Model 102's memory. The main scanning level contains the alphabet, numbers, punctuation, and commands. There are also four word levels, containing up to 120 words, and four sentence levels, with up to 56 sentences. The program also has an abbreviation expansion feature that improves the rate of message generation.

The user of BOCCA has a great deal of control over the operation of the system. Without leaving the scanning environment, the user can modify the vocabulary and various system parameters, such as the scan rate and the abbreviation expansion mode.

METHOD OF DISSEMINATION

Our method of disseminating this system is to provide it in the form of a do-it-yourself kit. The kit contains the scanning software, a single switch interface, and a comprehensive manual. An important part of the kit is the system manual. High quality system documentation is needed for two reasons. First, the complexity of hardware configuration and installation in a do-it-yourself kit makes comprehensive installation and troubleshooting documentation essential. Second, even in a pre-packaged system, instructions for using the installed system must be clear in order for the user to get the most enjoyment and productivity out of the system.

We have applied the concept of structured documentation in order to make BOCCA's manual as comprehensive and usable as possible. Many documents, such as the Trine System manual, employ structured documentation to produce very clear and helpful system guides.(2) The first task in preparing a structured document is to determine who will be reading it. The second step is to determine what concepts and information must be communicated to each of those readerships. These broad concepts are then successively broken down into smaller and smaller modules, much like "top-down" software design. Each of these modules presents a single idea or small group of related ideas to a specific target reader. (4)

The BOCCA documentation addresses two reader groups: those responsible for system installation and maintenance (typically a clinician or engineer) and the users themselves. Three sections of the manual are targeted at the system installers: an installation guide for the basic system, a reference section that describes optional expansions to the basic system, and a troubleshooting guide. A program listing and description are also included to allow more technically oriented system installers to modify the software. A separate part of the manual is a software use guide, targeted at the actual user of the system. This section combines tutorials with "hands-on" demonstrations to help the user learn about BOCCA as quickly as possible.

In addition to the kit, the user and/or clinician must obtain a Tandy Model 100 or Model 102 in order to complete the BOCCA system. Any of the supported peripherals or commercially available Model 102 enhancements can be used to expand the basic system. (see Figure 1) This do-it-yourself method allows the user (working with a clinician or engineer) to put together a very inexpensive and flexible scanning communication aid.

The low cost of the system is partially offset by the increased complexity of the system installation. Installation of the system requires a basic familiarity with computers. Fortunately, there are at least three sources of this level of technological literacy, so the user should have little difficulty finding someone to install their system. The first of these is the rehabilitation engineer. Rehabilitation engineering services are becoming more widespread, so many users now have access to a high level of technical expertise. In addition, most clinicians have had at least some experience with computers, so with the help of the BOCCA manual, they should be able to handle the installation process with relatively few problems. Finally, if the user does not have access to an engineer or a computer literate clinician, it it is very likely that a neighbor or local high school student will have the technical skills necessary to install the BOCCA system. Figure 2 shows a typical system setup.

We are marketing the BOCCA kit in two ways. The first is in conjunction with the Rehabilitation and Training Center at Tufts-New England Medical Center. The staff of the RTC is producing a catalog of all reprints, project summaries, and devices that are available through the Department of Rehabilitation Medicine. BOCCA will be

	BASIC SYSTEM	PERIPHERALS	ENHANCEMENTS
Degree of Installation Effort	Easy	Moderate	Easy to Difficult
Components	Model 100	Speech Synthesizers	Battery Packs
	Software	Printers	Display Enhancements
	Switch Interface		Others

Figure 1. System Components and Extensions

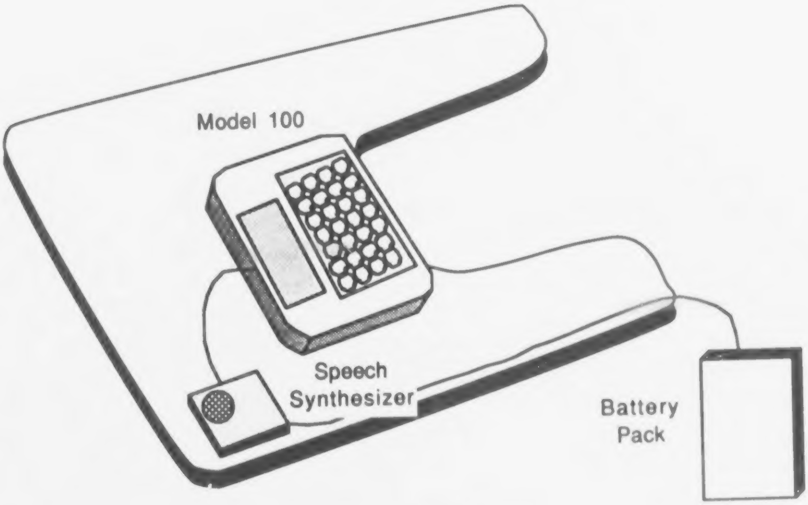

Figure 2. A Typical System Setup

included in this catalog, which will be mailed to rehabilitation professionals across the country.

The second marketing strategy is similar to the first. The Rehabilitation Engineering Center is putting together a catalog of devices and software that are solely products of the REC. The mailing list for this catalog will include potential users, clinicians, and equipment vendors. In this way, we will be reaching a broad representation of the rehab community, while continuing to pursue traditional technology transfer channels.

CONCLUSION

The major advantage to this method of dissemination is that it provides consumers with access to inexpensive, quality products that may be unavailable through commercial vendors. The price for this advantage is an increased burden on the consumer as well as the product's developer. The consumer now has the primary responsibility for system configuration and installation. As discussed above, a good system manual, combined with increased technological literacy on the part of the consumer, should make this process relatively painless. The product developer must take on the added responsibilities of marketing the product and producing high quality system documentation. However, we feel that most developers would rather assume these duties than watch a good product remain unused. Although this method is still being evaluated for its effectiveness, it has the potential to be a useful alternative to traditional technology transfer methods.

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The Implementation of a Software Methodology for Communication Aids

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ABSTRACT

A software design methodology previously developed has been applied to the development of a communication program for the IBM PC compatible family. Unique to this program is a high degree of flexibility in terms of the vocabulary structure, content, and presentation format, as well as system control parameters, input methods, and output devices. These features are realized through the use of standard structured design techniques that have resulted in the design of an extensible C function library that provides flexible communication system components.

INTRODUCTION

An increasing number of communication systems based on personal computers are becoming available to the consumer. The advantages of these systems include low cost, flexibility and reliability (6). Battery operated personal computers have extended these advantages to portable communication aids (1).

As technology has evolved, both the end user and developer have potentially benefited in terms of the overall functionality and power provided by personal computer based systems. This potential is only realized by the end user if the applications software takes advantage of this increased functionality. This places a greater responsibility on the developer to deliver software that is powerful in operation but not difficult to use.

BACKGROUND

A software development methodology for providing high quality extensible applications programs for augmentative communication has been developed and discussed previously (2). The five components of this methodology are:

- Standardization - Utilization of the same hardware and software tools in all development projects (4).
- Portability - Development of software that will execute in various hardware environments.
- Local Modularity - Design and coding of program modules or routines that may be used by various applications programs without alteration and repeated compilation.
- Global Modularity - A design strategy that produces programs suitable for integration in different application environments.
- Cross Development - Construction of programs on a powerful host computer for a clinically intended target machine.

These goals remain intact from the previous work with two exceptions. Previous work has been directed towards program development for the IBM PC, Apple II and Tandy Model 100/200 computers. Development is now restricted to the IBM PC architecture exclusively for the following reasons:

- Market trends have greatly lowered the purchase price for IBM compatible computers.
- There has been significant growth in the number of battery powered PC compatibles.
- The IBM PC architecture provides greater functionality for application programs.

The exclusive use of IBM PC compatibles has altered both the *Portability* and *Cross Development* methodology components. Portability has been refined to specify execution of a program within various PC hardware environments. For example, there is a wide range of display options available for desktop PCs (e.g., Monochrome, CGA, EGA) that should be supported by application programs. Cross development has been limited to the development of software on IBM AT compatibles intended for use on PC compatibles. This has become an almost trivial component of the methodology due to the inherent compatibility in the PC architecture (although differing clock speeds sometimes present problems).

The practical result of this methodology has been the development of a highly configurable augmentative communication and assessment package called *Nellie*. An additional result has been the development of a C library package that allows for the simplified construction of communication programs.

APPLICATION OF THE METHODOLOGY

The Nellie package is an augmentative communication system that provides a great deal of flexibility in terms of the vocabulary structure, content, and presentation format, as well as system control parameters, input devices, and output devices. The modular design of Nellie software allows it to support many different input methods. Early development efforts have focussed on several types of single switch input, and other input methods such as expanded keyboard, joystick, headmouse, and ocular control will soon be available. Each of these device drivers can be developed independently from the overall package and linked into Nellie when development has been completed.

Similarly, Nellie supports a wide range of output devices and hardware environments. This includes peripherals, such as printers and speech synthesizers, as well as a variety of display adapters and other PC-specific hardware.

The structure and presentation of the vocabulary is also extremely flexible. The number of selection levels is limited only by the amount of memory in the computer; a typical PC with 640K RAM could support over 100 levels of 8 rows by 8 columns.

Each level, or page, is made up of a group of "keys" that can be selected by the user. The keys can be arranged on the screen in any desirable format and can be displayed in several different sizes to aid visually impaired users. The contents of a key can be a letter, word, sentence (of any length), or a string of one or more commands.

This vocabulary flexibility, combined with the broad input/output device support, allows a clinician to truly customize the system for a particular user. For example, a cognitively able user can be provided with a full complement of words and sentences, as well as commands that allow him to edit his messages, expand abbreviations, and change his vocabulary or abbreviation list. These features can easily be "turned off" to provide another user with a much simpler system, such as a one-dimensional message scanner that speaks every selection.

Two utility programs, called *Setup* and *Bookmaker*, are included in the Nellie package to make it easy for the clinician to change the system configuration.

Using Setup, a clinician can specify the application environment parameters by selecting options from menus presented by the program. These parameters provide information about the specific communication application (e.g., the input and output devices being used), as well as the hardware environment in which that application will run (e.g., the video display adapter and output ports being used).

Bookmaker lets the clinician create a customized set of vocabulary pages for use within a given application environment. Pages can be be taken from a library of default pages, supplied with Nellie, or they can be designed from scratch. The program uses the same graphics display routines that Nellie uses, so the clinician can see exactly how any page will look once it's used in a communication system.

The alternative to using Nellie is to use a range of programs (at a minimum, one program for single switch scanning and one for direct selection). The use of Nellie instead of multiple single-use programs has many advantages for both the clinician and the user. Nellie provides a consistent clinician interface that facilitates reconfiguration of the program. This makes Nellie easier to use, because the clinician has to learn only one program instead of many. Once this single interface has been mastered, Nellie can be configured to meet most augmentative communication needs because it can be used as an assessment tool as well as a means of providing custom communication systems.

Users benefit from Nellie's flexibility in two major ways. First, it provides a very close match between the communication system and the user's abilities. The user can therefore be given as much control over the system as he/she can handle, minimizing the intervention of able-bodied attendants and increasing user independence. Finally, Nellie is easily changed in response to changes in a user's abilities. This means that the user no longer has to learn a new system every time his abilities change or, what is more typical, make do with a system that no longer fits his needs. It also makes the Nellie package very cost effective because it saves money that would otherwise be spent on the purchase and training costs of a new system.

EXTENSIONS TO THE METHODOLOGY

The driving force behind Nellie is a C function library called *Melvin*. Melvin is a conceptual outgrowth of the REC's robotics work. A major component of the robotics work was the development of a robotics development environment called *Calvin* (5). Calvin was originally developed as a C library and evolved into a complete interpretive development environment. Subsequent work has shown the need for both the Calvin library and environment (3). Melvin has been developed to be a comparable communication system development environment (i.e., Melvin is Calvin's brother). Current work has focused solely on the development of the Melvin library.

The Melvin Library consists of a number of major independent modules arranged in a functional hierarchy (Figure 1). There are three levels in the hierarchy. In addition, the Melvin library uses three other commercially available C function libraries.

Level 1

The lowest level of the Melvin library consists of the basic system primitives arranged in four separate modules. The Data module manages system memory usage and provides other Melvin modules with a simplified access to the Melvin data structures. The Melvin data structures are a powerful representation of communication system data. They store information about the individual page contents as well as the application environment parameters. The Display module contains all screen functions, including discrete character and string display primitives as well as higher level data structure display routines. The Input Device module consists of all hardware drivers used for the different input modes that Melvin supports. Example devices are joysticks, mouse input, and touch sensitive tablets. The Output Device module contains all output drivers for speech synthesizers and printers.

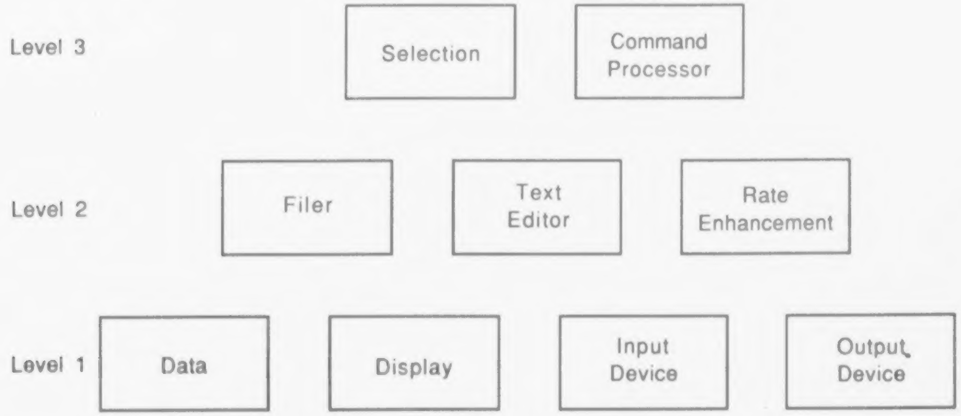

Figure 1. Structure of the *Melvin* Library

Level 2
The middle level of the library consists of three modules. The Filer module handles all disk input and output operations with extensive error checking. For example, before attempting to read from a disk, Filer will check to see if the disk is inserted in the drive to avoid the common MS-DOS error "Error reading Drive ...". The Text Editor module functions as a stand-alone one line text editor with a full set of edit functions. This editor will be expanded to have a configurable number of lines in future versions. The rate enhancement module consists of a number of separate rate enhancement functions such as abbreviation expansion and letter predictive algorithms.

Level 3
The top level of the Melvin library is actually two separately compiled object modules. These modules remain separate because most actual programming with Melvin consists of modifications to the source files of these modules. The Selection module consists of a high level description of the input mode (e.g., scanning). If a developer wanted to create a unique input mode (e.g., have two successive switch hits indicate selection), he could modify the Selection module by changing the way the single switch input function is handled. The Command Processor module is responsible for processing of all selected commands within the communication system. This module can be modified to add new commands. For example, the program Bookmaker uses a different set of commands within the Command Processor to allow the clinician to design page layouts for a particular patient's system. Although these two modules would not be considered part of the library in the strictest sense, they do provide a fairly complete shell for any new development.

External Libraries
As stated previously, the Melvin library does require the use of other commercially available libraries. The current libraries in use are the Greenleaf Functions, the Greenleaf Asynchronous Communications Library, and the Metawindow graphics library. The Greenleaf functions provide a variety of system utility functions. The Greenleaf Comm library provides interrupt-driven RS-232 communications routines. The Metawindow library provides graphics routines that allow variable size fonts and future extensions to pictorial representation. The major advantages of using external libraries are a significantly reduced development and maintainance efforts and broader hardware support (e.g., Metagraphics supports over 100 graphics boards/modes).

DISCUSSION

The development of the Melvin library represents an extension of both the previously presented methodology and the REC's research in robotics. Furthermore, it is consistent with trends that have unfolded in the commercial software arena. Many commercial software developers use third party function libraries in the development of their own application programs. One example of the usefulness of library based software is that the programs Nellie and Bookmaker although quite different in function share approximately 80code.

There are two major goals for this project in the near future. The first goal is to extend the functionality of the library. These extensions will include:

- Increased input and output device support
- Implementation of pictorial graphics
- Multi-line text editor
- Improved granularity of library to improve memory usage and eventual overlay linkage
- Incorporation of Multi-tasking based computer access

The final goal of this project is to provide a software environment similar to Calvin, the robotics environment. To accomplish this, two major areas are being considered. The first area is an analysis of what aspects of a communication system need programmability. In the commercial software arena, different applications need differing amounts of programmability. For example, while spreadsheet programs (e.g., Lotus 123) generally provide macro capabilities to define new commands, many database programs (e.g., Dbase III) come with a full programming language for application development. The analysis of progammability will be accomplished to a large extent by Beta testing of the Nellie program.

The second area that will be investigated (in joint consideration with Calvin) is what development environment technology is best suited to the needs of this area. Several technologies exist including interpreters, incremental compilers, and the use of commercial environments that are linkable with external libraries.

CONCLUSION

As clinicians become more computer competent and rehabilitation engineering service delivery becomes more established, there will be an increased need for systems that offer that increased flexibility. The programmability that is inherent in many commercial business applications should be available in communications systems. When this technology is in place, the full potential of personal computers as rehabilitative aids will be realized.

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THE ARCHITECTURE OF AN EXECUTIVE WORKSTATION FOR THE DISABLED

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ABSTRACT

The goal of this project is to develop a computer-based workstation to improve the career opportunities as well as the productivity of the motor impaired in a professional work setting. To provide flexibility in this system we have developed a triple-layered software design. Through the use of this three layered architecture we have realized greater support flexibility for device, context, and individual require-ments. These layers support: 1) device specific input interface 2) man/machine interaction manager, 3)application interface manager. This architectural approach allows us to make major changes in one layer without necessitating significant changes in the remaining software. This approach allows graceful adaptation of the system to many individuals' needs with maximum developmental efficiency.

INTRODUCTION

Industry and academia are becoming involved in the development of professional electronic work environments at a steadily increasing rate. Unfortunately this research has not considered the needs of disabled users. The likely increase in productivity for the disabled is greater and a workstation supportive of them can open career opportunities that would not be possible without this technology. We have begun to develop a flexible workstation that will allow for graceful adjustment of the system to meet the individual needs of the user. This system will also provide access to the same functions that are being developed in workstation research for professionals in general.

To meet this goal we have identified three functional areas that must be addressed in a workstation for the motor impaired professional.

1) Basic communication. The mode of input must take advantage of the individual's capabilities. Conventional input devices (e.g., keyboard) often do not meet this criteria. Innovative input devices such as retinal reflection and electroencephalograph monitoring are being investigated as possible input modalities by many research groups. The system must have the capability for interfacing with new technologies as they become available.

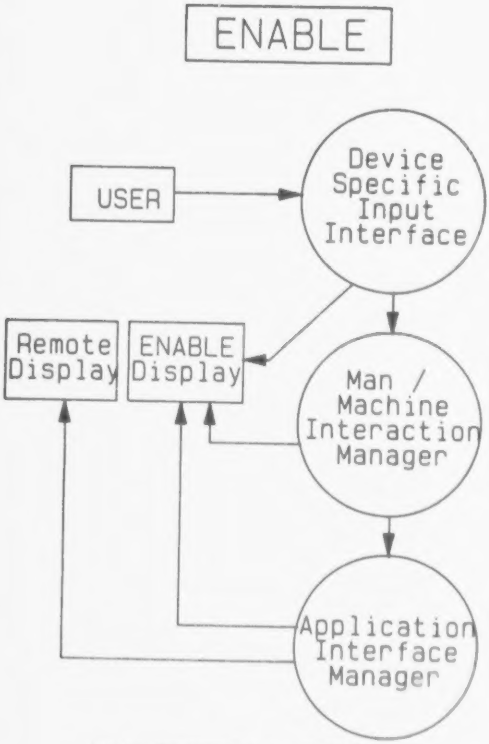
2) Access to appropriate professional reference materials. The able-bodied can manipulate books and charts to obtain access to reference information that they need for the completion of a task. Similar activities are a major undertaking or, in some cases, an insurmountable barrier for the physically disabled. It is already possible to purchase dictionaries, thesauruses and other general reference materials from a number of sources. However, many of these software packages are not easily integrated with other programs.

The majority of general reference material is static. The storage requirements for such material and attendant access structures requires large amounts of digital mass storage. The expense of manufacturing optically stored reference material is already attracting commercial products because of the low cost of replication of the media and potential high volume of sales. The use of video disk technology for materials that need not be digitally manipulated is an attractive alternative. Methods of accessing this technology must be well integrated with the other operations of the system to be effective.

3) Context specific assists. Assists specific to the performance of a task that is being carried out are needed by the disabled user. Even with improved input support and efficient access to reference material, the additional effort that is required of the disabled user, increases the "cognitive load" on the individual. These additional demands on finite mental resources, curtail the effectiveness and creativity of the individual. In order to partially compensate for these intellectual demands, task specific aids should be available. Such aids must provide support for deciding between alternative approaches as well as methods for efficiently carrying them out. While such aids are desirable in any supportive work environment, this form of assistance is essential for the disabled.

SOFTWARE DESIGN

The disabled professional population has significant variance in terms of physical and task associated needs. This necessitates a flexibly designed workstation. To insure flexibility we have developed a software architecture divided into three layers. This layered software design has been employed to allow functional differentiation between modules of the overall system.


ENABLE
USER
Device Specific Input Interface
Remote Display
ENABLE Display
Man / Machine Interaction Manager
Application Interface Manager

Major Components of ENABLE (alpha version) system

Layer One: Device Specific Input Interface. The software in this layer maps signals from a specific input device into a standardized device interface response set. By modifying this layer it is possible to support devices as varied as a joystick or voice-recognition system without modification of other layers. This layer also provides the natural implementation point for mechanisms for adjusting low-level parameters, such as the amount of movement necessary with a joystick to signify an input. This allows optimization of the physical device interface for the specific individual.

Layer Two: Man/Machine Interaction Manager. This level translates the device interface response set into a specific set of pre-determined selections. These selections are used in two ways. One use is to cause a character or group of characters to be forwarded to application activities (layer three) as though they were entered through normal means. The other use of these selections is to provide access to additional interaction choices or functions.

Layer Three: Application Interface Manager. Task specific assists are managed in this layer. Modules such as word completion, formatting assists and access to various forms of reference material can be dynamically adjusted to meet the users needs in a timely fashion. This layer coordinates assistance functions and transmission of information to application software.

Assistive functions are used to enhance activities of the user in performing a specific task. These functions provide a set of "most" likely next action sequences, from which the user can select one for automatic implementation. A simple example of such an assist would be selecting the completion of a word from a list (which is based on recently entered characters and the specific context).

CURRENT HARDWARE CONFIGURATION

Both the alpha and beta versions of the ENABLE system require an IBM PC compatible microcomputer with 512K bytes memory, a floppy disk drive (preferably hard disk drive), serial communication port, analog input card (joystick interface), and a color graphics adapter (CGA) and display. At present a separate "dumb" ASCII terminal is used to display the application activities when the system is in use with a remote system (such as the UNIX system on a remote, multi-user system).

RESULTS

Testing of an alpha version of the system has been conducted and shows that subjects increased their speed across the testing period (approximately 7 sessions over two months time). The initial speed at which the subject entered characters was inversely correlated with their use of word completion.

FINAL COMMENTS

A beta version of the system that will allow the user to interactively customize the system is under development and limited testing.

ACKNOWLEDGEMENTS

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FEATURES TO INCREASE THE ACCESSIBILITY OF COMPUTERS BY PERSONS WITH DISABILITIES: REPORT FROM THE INDUSTRY/GOVERNMENT TASK FORCE

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Charles C. Lee
Lawrence A. Scadden
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ABSTRACT

In 1984, representatives of the major computer companies met with researchers, consumers, and government personnel to discuss the issue of computer access by disabled persons, and the role that standard computer manufacturers might play in enhancing access for disabled persons. This led to the formation, two years later, of the Industry/Government Task Force on Design of Computers to Increase Their Accessibility by Disabled Persons. This is a voluntary, advisory group whose objective it is to identify the primary difficulties faced by disabled persons in the use of standard manufactured computers as well as possible approaches for reducing the difficulties. The Task Force also helps to identify those current features of standard microcomputers which facilitate their use by disabled persons, so that the features might be enhanced and not lost. The two products of the Task Force to date have been a list of features/capabilities (presented here), and a more extensive document titled "Considerations in the Design of Computers and Information Processing Systems to Increase Their Access by Persons with Disabilities."

The majority of the items identified were found to have direct implications for increasing the usability of the computer systems by nondisabled persons as well. Most aspects targeted for disabled persons could be implemented in future computer systems on a low-cost or no-cost basis.

MECHANISMS FOR MAKING COMPUTERS MORE ACCESSIBLE

Features which would make computers more accessible can basically be broken down into two groups:

a) features which allow persons with disabilities to access and use computer that are not owned by or assigned to them (public or shared computers);

   Type 1) features that allow individuals with mild impairments to use the computers directly as they come from the box;

   Type 2) features that facilitate the connection of specialized interfaces and accessories for individuals with more severe disabilities.

b) features which facilitate the use of computers which are personally owned or controlled by the disabled individual;

   Type 3) features that facilitate customization of a personal computer to allow access to standard software;

   Type 4) features that make computer use easier but are not required for access;

   Type 5) features that facilitate special applications for computers.

For companies interested in enhancing access to general use computers, it is the first group (types 1 and 2) that is of the highest priority. These features allow people with disabilities to use computers as they come across them - rather than having to disassemble or modify the computer or its software in order to gain access.

Figure 1 provides a listing of some (not all) features from each of these categories. Many of these modifications can be implemented in software, often as relatively minor modifications or extensions to the operating system of the computer. As such, they do not increase the manufacturing cost of the computer. Even hardware design modifications, which would be very expensive on a retrofit basis, can usually be implemented without increase in manufacturing cost on future systems. In Figure 1, those items which could be implemented through software modifications are marked with an asterisk. Note that most of the modifications would increase the flexibility or ease of use of the computers for the non-disabled "mass market" as well.

THE MULTIPLIER EFFECT - ARE ACCESSIBLE DESIGNS THE MASS MARKET DESIGN?

While many of the design features implemented for individuals with disabilities will also benefit the mass population, there are some features which can be implemented which are really only of direct benefit to those individuals with more limited abilities. Implementing these features may not seem to be as economically sound as those features which also benefit the mass market. After all, in general, products are designed to address the bulk of the market, and only take small market segments into account if they can be implemented on a no-cost or low-cost basis. Individuals who have disabilities, even though they represent 20% of the population, are still a minority of the population. When it is further realized that 20% represents all of the disabilities, and any particular disability is only a portion of that number, the justification for specialized adaptations or accommodations is reduced further.

There are, however, several multiplying factors which make the impact of this market segment greater than it first appears. Most of these factors deal with the fact that marketing of computers is generally not targeted at individuals, but at groups of individuals (e.g., a company, a school, etc.). In general, people buying computers for that group or organization would like to buy computers which can be used by everyone in that group/organization. If everyone in that group/organization cannot use the computer, and the computer becomes an integral part of that group's or organization's activities, then there will be some of the members of that group who will be unable to function in the group. In a school, this would translate into children who were unable to participate in the regular classrooms that used computers. In a company or agency, this would translate into individuals who were unable to be hired into or retain jobs which required access to and use of the computers being purchased.

The result is that, although only 20% of the population is disabled, the percentage of companies, agencies, schools, etc. which would like to allow disabled persons to work in the same environments and on the same computers as their able-bodied peers is closer to 80%. If computers are being

FIGURE 1:
FEATURES WHICH ALLOW/FACILITATE USE OF COMPUTERS BY PERSONS WITH RESTRICTED ABILITIES

TYPE 1: FEATURES THAT ALLOW MORE PEOPLE TO USE THE COMPUTER AS IT COMES FROM THE BOX:

- Allows access to standard software without requiring modifications.
- Needed for access to public/shared computers (school, company, community) (also Type 2, for more severely impaired persons).

PHYSICAL IMP:	* Keyboard operable with 1 hand (1 finger or mouthstick, etc.) (invokable feature).
	* Mouse cursor completely controllable from the keyboard (if system has mouse).
	* Touchscreen/touchpad completely controllable from the keyboard (if system has touchscreen/touchpad).
	● Separate keyboard (movable/positionable).
	* Key repeat defeatable.
	● Disks easy to insert and remove (e.g., with arthritic hands, or using tongs held in mouth).
	● External disk drive that can be used to boot (allows special positioning of drive).
	● Slide, thumbwheel, pushbutton (or keyboard operable) controls (if required for system operation).
	● On/off from front of computer.
VISUAL IMP:	* Zoom or screen image enlargement feature (full screen access required).
	● Large high contrast letters on keyboard.
	● Nibs on home and important peripheral keys (ESC, Backspace, DELete).
	● Standard location of keys
	* Colors user specifiable (including black on white versus white on black), or color information redundant.
	● Separate monitor (repositionable).
BLINDNESS:	-- Nothing for BLINDNESS in TYPE 1 FEATURES: see TYPE 2 FEATURES.
HEARING IMP:	● Volume controllable (plus reasonably high volume level possible).
DEAFNESS:	* Visual display of any beeps, sounds, or speech output.
COGNITIVE IMP:	* Consistent, simple format and language, non-memory based.
	* Reversible actions.
	* On-line Help.

TYPE 2: FEATURES THAT ALLOW CONNECTION OF SPECIAL INPUT/DISPLAY DEVICES TO COMPUTERS:

- Needed for access to public/shared by persons with moderate to severe sensory/physical impairments.
- Allows access to standard software.

PHYSICAL IMP:	* Standard alternate input connection point (external) (input treated identically to standard input devices). (allows connection of wide variety of alternate inputs -- eyegaze, headpointing, morse, voice, etc.)
BLIND/VISUAL IMP:	* External connection point where screen display contents are available. (allows connection of different alternate display devices -- Braille, tactile, voice, etc.)
HEARING IMP:	● Headphone/audio connection point.

TYPE 3: FEATURES THAT FACILITATE CUSTOMIZATION OF PERSONALLY OWNED COMPUTER TO ALLOW ACCESS TO STANDARD SOFTWARE (Types 1 and 2 above would also apply here)

PHYSICAL IMP:	* Injection point in system where a background program can inject keystrokes and mouse/touchpad actions.
	* Phantom window which stays above active windows (invokable -- lasting).
	* Standard system drivers/structure for all types of input (facilitates design of compatible alternatives).
	● Switch input point (jack or dedicated pins on other connector).
	● Provision for keyguard mounting (e.g., groove on sides of keyboard, etc.).
BLIND/VISUAL IMP:	● Connection point for larger displays (e.g., video connector).
	* Built-in voice capability (facilitates voice output of screen information).
ALL	● Open architecture (plenty of slots).
	● Manuals in electronic form (ease of handling; allows alternate display forms).

TYPE 4: FEATURES THAT MAKE COMPUTER USE EASIER BUT ARE NOT REQUIRED FOR ACCESS

PHYSICAL IMP:	* Key repeat/delay user adjustable.
	● On portable computers, latches operable with one (very arthritic) hand or mouthstick, etc.
	● On portable computers, space inside case for permanently mounted keyguard.
BLIND/VISUAL IMP:	● Manuals in Braille or voice (or electronic).

TYPE 5: FEATURES THAT FACILITATE DESIGN OF SPECIAL APPLICATIONS FOR COMPUTERS (BUT NOT REQUIRED FOR ACCESS TO STANDARD APPLICATIONS SOFTWARE)

- * Built-in voice capability (blind, speech impaired, deaf-phone).
- ● Ability to route computer sound (speech) through modem (speech impaired, deaf).
- ● On portable computers, pretapped holes on bottom (to attach special accessories).
- ● Portables flat when closed.

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* indicates feature could be implemented in system software

designed for these "group" markets rather than just selected individuals within these groups, then "groups which include individuals with some type and degree of disability" becomes the "mass market" or target market.

As computers have moved from optional productivity tools to required tools on the job or in the classroom, this has become increasingly clear. School systems have let out requests for bids for computer purchases stating that accessibility for their disabled students was required in order to qualify. The U.S. Congress, as part of the new Rehabilitation Act, has also acted to help ensure that computers and office automation equipment purchased by the government would meet minimum accessibility standards. Section 508(a) of the revisions to the Rehabilitation Act state:

> "Sec. 508(a)(1) The Secretary, through the National Institute on Disability and Rehabilitation Research and The Administrator of the General Services, in consultation with the electronics industry, shall develop and establish guidelines for electronic office equipment with or without special peripherals.
>
> "(2) The guidelines established pursuant to paragraph (1) shall be applicable with respect to electronic equipment, whether purchases or leased.
>
> "(3) The initial guidelines shall be established not later than October 1, 1987, and shall be periodically revised as technologies advance or change.
>
> "(b) Beginning after September 30, 1988, the Administrator of General Services shall adopt guidelines for electronic accessibility established under subsection (a) for Federal procurement of electronic equipment. Each agency shall comply with the guidelines adopted under this subsection.
>
> "(c) For the purpose of this section, the term special peripherals means a special needs aid that provides access to electronic equipment that is otherwise inaccessible to a handicapped individual."

This action was taken in response to a concern that the increasing use of computers and office automation equipment in the government could significantly impact on disabled government employees. It was felt that, as computers became mandatory parts of the job, inaccessible computers could cause individuals with disabilities to lose their positions, be unable to be hired into positions, or block their promotion or transfer into positions requiring computer use. Even the Department of Defense has particular interest, due to a concern for disabled veterans.

Although the NIDRR/GSA Guidelines have not yet been drawn up, they are expected to be general performance guidelines in nature. The objective is to provide industry with a clear indication of what would be required to provide "reasonable accessibility," while leaving the actual method for achieving this up to industry. This type of flexibility would be essential to prevent hindering innovation and advancement in this important area.

CONCLUSION

There are may ways in which current and future computers could be designed to make them more usable by persons with disabilities. Most of these are no-cost or low-cost in nature, and benefit nondisabled users as well.

Two efforts ongoing at the present time in this area are:

1) Industry/Government Initiative on Computer Accessibility: A voluntary effort targeted at generating better information for industry and facilitating cooperative efforts in this area. (Anyone may join this effort by writing to Dr. Gregg C. Vanderheiden or Dr. Lawrence Scadden – see below.)

2) NIDRR/GSA Effort to develop procurement guidelines for government purchase of electronic office automation equipment including computers.

NOTE: The list of features in Figure 1 is not meant to be exhaustive, nor should it be seen as a checklist for accessibility. It is merely presented as a listing of examples of the types of features which might be provided for current generation computers to increase their accessibility.

Anyone wishing more information on this topic area, or wishing to join in the Industry/Government Initiative (which is open to all) should contact:

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Special Interest Group 12

Rural Rehabilitation

Chair: Don V. Mathsen, M.S.

INTERNATIONAL ASPECTS OF RURAL REHABILITATION
INTRODUCTORY SYMPOSIA STATEMENT

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INTRODUCTION

United Nations' estimates indicate there are approximately 500 million disabled individuals of whom 400 million live in isolated rural areas in developing countries. In some countries, the disabled constitute 20 percent of the population. Usually, the disabled persons are extremely poor and live in areas where medical and other related services are scarce or even totally absent. In China alone with nearly one quarter of the earth's population, 850 million, or nearly 85 percent of the population work the land. Worldwide, it is estimated that at least 350 million disabled persons live in areas where the services needed to assist them are not available. Estimates also indicate the number of disabled will double by the turn of the century (1).

Thus, the global problem of disabilities is centered in the rural environment. While advances in technology are rapidly creating new opportunities and solutions in addressing the needs of the disabled, many of these advances assume and depend upon a highly-developed environment in which to function. It is the purpose of this symposium to create an awareness of the needs and opportunities for rehabilitation service delivery and practice among the rural disabled on a global perspective.

The fundamental question is: How can appropriate technologies be developed to meet the needs of rural disabled individuals? Correspondingly, what can the developed countries learn from the experiences of rehabilitation professionals and laypersons working in rural Third World regions of the world. Within this scope, the symposia will reflect the experiences and observations of U.S. professionals who have spent time in China and the Latin American countries.

BACKGROUND

On the continents of Asia, Africa, and Latin America over eighty per cent of the disabled live in rural areas in a variety of cultures, religions, and social settings. Generally, however, rural disabled individuals do not like to be uprooted from family and their native environment, resist moving to an urban environment, and experience detrimental financial and psychological effects from relocation. Rehabilitation is most effective, therefore, when conducted within a comfortable environment of accustomed employment, vocational, and socio-economic settings(1).

Optimizing rehabilitation service delivery in the rural areas of the world is a major task. United Nations programs have begun to address these needs. The U.N. World Programme of Action Concerning Disabled Persons emphasizes coordinated programs of prevention through community-based primary health care systems. This program has worked for government programs to aid the disabled, encouraged equal standard of living provisions, promoted employment opportunities, and addressed the problems of rural life with disabilities. As part of International Youth Year, 1985, the U.N. encouraged governmental policies creating equal employment opportunities and research programs for disabled youth in both urban and rural settings. In declaring the period 1983-1992 the Decade of Disabled Persons, the U.N. General Assembly has recognized the challenge and created the impetus for international cooperation to overcome centuries of neglect.

The failure of the traditional institutional model in providing rehabilitation services in developing countries has led to a greater reliance on early detection and management using low-cost technology and local community resources. The World Health Organization (W.H.O.), in response to the 29th World Health Assembly in 1976, developed a manual entitled, "Training the Disabled in the Community" which has been used successfully in India (2).

Within the U.S., the National Institute on Disability and Rehabilitation Research, formerly NIHR, has sponsored the PATH Americas program on resources and low cost technologies in Latin America. Several of the World Rehabilitation Fund international fellowships and monographs have identified applications for U.S. rehabilitation practices and have taken U.S. service delivery ideas abroad (3).

Under the support of the Hesparian Foundation, Project PROJIMO in Western Mexico was an innovative response to the need to train family and local community members to work in the village home environment of the rural disabled. This program sought to give families the understanding and skills to enable their disabled children to reach their full potential. As an affiliate of Project Piaxtla, Project PROJIMO had the benefit of coordination with a well-established villager-run health care network in which local village health promoters provided the infrastructure for primary medical care (4).

As the developing nations become dependent on more mechanization for agricultural and other rural economic activity, the occurence of accidental disabilities will increase. Though no official data exists, the Chinese Ministry of

Agricultural Machinery received reports of more than 3,000 tractor and machinery-related deaths and 4,000 serious (amputation or spinal) injuries during 1980. In comparison, the U.S. reported 1700 deaths and 180,000 disabling injuries from ag-related accidents in 1984. Thus, the impact of mechanization has just begun to have a global impact on rural disabilities (5).

SUMMARY

Rural residents as a group enjoy the 'values' of their lifestyle. Successful rehabilitation occurs when it allows the disabled individual to retain those 'values' and permits a lifestyle where individual confidence and familiarity with the environment is maintained. Technology is only one piece in the puzzle. Technology must find its appropriate place, particularly if the local infrastructure will not support its application and maintenance. Disabled individuals in developing regions of the world will be benefited the greatest when the rehabiliation service delivery infrastructure is integrated at the family and community level.

The responsibility of the rehabilitation professionals, and particularly the research community, of the technologically-advanced countries is to maintain a world-wide perspective. Where technology can provide a solution, simplicity in design and maintenance of devices is especially crucial for widespread application in the rehabilitation field. Furthermore, patient-oriented technology must be integrated with the service delivery mechanisms which make it available to the disabled individual. As an example, the application of sophisticated prosthetic devices for individuals living in environments where service and maintenance of the units is not available generally does not result in long-term usage of the product

Sharing information and developments between the technologically advanced countries and the developing nations can benefit everyone. New technologies can be judiciously applied in the developing countries while the successful resolution of disability needs using indigenous materials within a 'low-tech' environment can often lead to new insights for developing cost-effective services and devices in even the most technologically-advanced nations.

Advances in telecommunication and transportation systems will expedite the exchange of rehabiliation practices among nations. Since markets for rehabilitation hardware and techniques will always be limited in any one country, the potential for sharing developments around the globe enhances the commercial base from which manufacturers and service providers can develop and market their products and services. From this commercial perspective, the unique challenges of rehabilitation requirements in rural areas should be key design parameters in eyes of manufacturers and service agencies.

Since many of the technical aspects of rural rehabilitation practice consist of 'one-of-a-kind' solutions to problems associated with disabilities, international cooperation in the cataloging and sharing of these devices should be enhanced. Likewise, there are technological niches which exist in various countries which need to be brought to the attention of the general rehabilitation, and particularly the rehabilitation technical community. As an example, a Swedish manufacturer and research group has made major strides in the development of hand controls for the operation of construction and farm equipment which allow both able-bodied and disabled operators to easily control the operation of farm and construction for long durations.

In summary, international cooperation benefits all nations and all disabled individuals in the field of rehabilitation technology. The discussion at this conference will help to further this dialog.

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AGRICULTURAL-RELATED DISABILITIES IN CHINA/A PERSPECTIVE

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ABSTRACT

The following paper provides a brief overview of the problem of agricultural-related disabilities in China. It considers the primary causes, prevention measures, and the application of rehabilitation technology in rural areas. It is based on observations made during two, six week visits at the Luoyang Tractor Research Institute in Luoyang, Henan.

INTRODUCTION

China is an uncomprehendable nation, with an uncomprehendable number of people facing opportunities and problems that no one person could ever get a handle on. Broad generalizations made about this nation, with respect to any issue, are usually of little value and often lead to distorted perspectives and incorrect conclusions. The following observations are made with these parameters in mind.

Because of the potential scope of the topic, my comments will focus on agricultural-related disabilities in China from two points-of-view. First, the need for disability prevention measures and second, the potential for the application of basic rehabilitation technology.

Rural Nature of China

No country on earth can be more accurately described as rural than China. No where is more human effort expended specifically to feed and cloth a people. Even considering its limited reliance on modern agricultural technology, China has nearly achieved the point of adequately feeding over a billion people on less arable land than found in the United States.

It is estimated that between 80 and 85 percent of the total Chinese population is directly engaged in agricultural production. Translated into actual numbers, this suggests that the Chinese agricultural work force is somewhere between 800 and 850 million people. The discrepancies in the data alone, due to a lack of accurate census information, are nearly 10 times the present farm population of the United States. In terms of potential work-related disabilities, there is no nation in the world that has more people exposed to the health and safety risks associated with the agricultural work place.

The scope of Chinese agriculture ranges from tiny backyard plots of vegetables to communes that cover hundreds of thousands of hectares involving thousands of workers and families and producing everything from Peking ducks to lychees. China's diverse climate allows for a broad variety of crops with the principal food grain, not only in terms of area sown but amount harvested, being rice. In addition, considerable amounts of wheat, corn, cotton, and fresh vegetables are raised. Nearly one-third of all China's crop land is irrigated which is unparalleled anywhere in the world. China is also a major producer of livestock, fowl, and freshwater fish.

Scope and Magnitude of the Agricultural-Related Disability Problem

There are no available data on the losses resulting from farm-related accidents or occupational illnesses and such data will not be available in the foreseeable future. China, unlike the United States, does not tend to report or dwell on bad news, and farm-related accidents fall in the category of bad news. While visiting with staff members of the Ministry of Agricultural Machinery in Beijing, it was indicated that the ministry had received reports of more than 3,000 tractor and machinery-related deaths and 4,000 serious injuries during 1980. Considering that there was no coordinated effort to gather farm accident data and that there was a built-in reluctance to negative reporting, the actual problem was probably much greater. The near equal number of deaths and injuries further suggests that only the most serious injuries were reported. This was partially substantiated in the case histories mentioned which involved permanent disabilities such as double amputations and spinal injuries.

From discussions with Chinese agricultural officials, it appears that the major sources of work-related traumatic injuries which result in permanent disabilities are as follows:

1. Machinery-related accidents. China has taken major steps towards agricultural mechanization. Each year thousands of new farm machines are manufactured and introduced into the countryside. These machines reduce the labor demands and drudgery, but expose the farmer to the risks of serious injuries. Stationary, engine-driven crop processing equipment such as flour mills, hammer mills, and cotton gins were frequently reported as being involved with lost limbs. It is estimated that over 2 million small grain threshers are in use which presents considerable exposure to unguarded belts, chains, and other moving parts.

2. Tractor and rural highway accidents. Each year about 120,000 riding wheel and track-type tractors are being produced along with approximately 300,00 diesel-powered walking tractors. In addition to the risk that this equipment presents to the operator in the field, it is estimated that 80 percent of the riding wheel tractors annual usage is for transportation on public roads. In highway accidents, the greatest risk is to the extra riders on the tractor and pedestrians.

3. Electrocutions and fires. Electrical power is slowly becoming available throughout rural China. It is often installed with limited understanding of the potential hazards. Burns are an age old and tolerated problem of a rural population that depends on open fires for heating and cooking. With the introduction of liquid fuels, the risk of both fire and explosion have increased.

An examination of the potentially disabling health problems of the Chinese farmer, from a North American perspective, would suggest that the situation is not good. These problems include:

1. Exposure to high concentrations of dust. Exposure to agricultural dust is a hazard facing millions of Chinese farmers especially during harvest. The extensive use of small mechanized threshing units greatly increases the proximity of the worker to the dust source. At the commune health clinics visited, it was noted that severe respiratory ailments were a major complaint.

2. Exposure to agricultural pesticides. Even though the use of pesticides is on a much smaller scale than found in North America, their use is expanding rapidly. The introduction of pesticides, often with only limited training, has undoubtedly increased exposure and has the potential for the development of chronic health problems.

3. Exposure to high levels of noise. Noise pollution is an unescapable problem in China. With newer equipment that often operates at noise levels in excess of 90 dBa, the potential for premature hearing loss greatly increases. This is especially true since little personal protective equipment is used.

4. Exposure to zoonotic illnesses. In general, there appeared to be little concern for or awareness of the potential risks to health from exposure to livestock and human wastes. The use of raw manure in fields where nearly all the work was being done by hand and worker exposure to contaminated runoff was high, were common sights.

Reducing Disabilities Through Prevention

Serious efforts to improve the conditions which contribute to agricultural-related disabilities will only occur as the quality of rural life in China improves. Historically, the Chinese farmer's greatest physical threats were associated with hunger, disease, and civil disorder. No where in the world, for such an extended period of time, have more farmers, on the basis of sheer numbers, lost their lives in the process of tilling the soil. Risks that would appear foolish or even suicidal by standards in the Western world were and often remain essential daily tasks for the Chinese farmer and members of his family.

Failure to produce a good harvest in early China had ramifications that were uncomprehendable. There were few risks that were too great to accept and often the selection did not include a safer or healthier alternative. Failure to understand or take into consideration the roots from which rural China has grown makes it impossible to appreciate the level of acceptable risk presently found in Chinese agriculture.

It appears that North American agricultural engineers, technicians, and safety professionals have much to offer to their Chinese counterparts to reduce the physical risks of agricultural production and still maintain high levels of productivity. This includes concepts of machine guarding, reducing noise levels, techniques for safe handling of agricultural chemicals, improving personal protective equipment and methods of operator training.

Rural Rehabilitation Technology Needs

As with prevention of disabling injuries, the application of rehabilitation technology to the rural areas of China is not a very high priority. This was illustrated during a factory tour when I noted to the manager that no one was wearing safety glasses. His response was based purely on the economics of both prevention and rehabilitation. To equip everyone with safety glasses was more costly than caring for those who became visually impaired due to an injury. In other words, the cost of prevention is too high and the investment into rehabilitation efforts is low.

There is, however, a growing interest in rehabilitation issues since the son of Deng Xiao Ping was appointed to expand the services to the disabled population. He had received a spinal cord injury when thrown from a building during the Cultural Revolution.

As rehabilitation technology gains ground in China, it seems appropriate that there be a continued dialogue between professionals in China and North America. There would be mutual benefits for both groups. Chinese professionals would have access to the new technology of rehabilitation and North American professionals would be reminded that the simple approach is often quite adequate.

A meaningful dialogue could be developed through the following measures:

1. Exchange of technical information and resources between organizations, such as RESNA and their appropriate counterparts in China.
2. Invitations to Chinese rehabilitation technology professionals to attend and observe the activities of groups such as RESNA.
3. Establish one or more rehabilitation technology assistantships at universities in the United States to provide young Chinese rehabilitation professionals with an exposure to the most recent applications of technology to rehabilitation problems.
4. Conduct an exchange of educational and scientific tours to give Chinese and American counterparts an opportunity to share ideas and observe first hand problems each other are facing.

SUMMARY

There is always much more that can be gained through cooperation and sharing.

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PUTTING THE TOOLS IN THE HANDS THAT CAN USE THEM:
Wheelchairs in the Third World

Ralf Hotchkiss, Director
Appropriate Technology for Independent Living

This presentation describes the efforts of a worldwide team of wheelchair riders, designers, entrepreneurs, and engineers to make low-cost, rugged, state-of-the-art wheelchairs available in developing countries. After six years of work a lightweight sports chair has been designed, and 20 groups in Latin America, Asia and Africa have begun manufacture. Sponsored initially by Appropriate Technology International in Washington, D.C., the work is now being continued by Appropriate Technology for Independent Living, a project of Tools for Living in the Community of California.

MOST PEOPLE WHO NEED A WHEELCHAIR DON'T HAVE ONE

In Third World countries, most disabled people who need a wheelchair simply don't have one. In India and China there may well be 10,000,000 individuals who need, but don't have, a wheelchair. The few chairs in use tend to be heavy and are too wide to fit through narrow doorways. These chairs are often in need of repairs, requiring parts that cannot be found locally. Of course, high cost is the reason most people don't have a chair. A wheelchair at current prices is out of reach both of most disabled people and of the social programs of most Third World governments.

As a disabled person myself, I began working on wheelchair design because I wanted a better wheelchair, almost regardless of the cost. This project has been quite an education for me, as it has become clear how much the high cost of a good wheelchair must be reduced before most of the World's disabled people will be able to own one.

New wheelchair manufacturers are springing up throughout the developing world; probably well over 100 have begun operations in the past 5 years. Most of their chairs, unfortunately, have been derived from the heavy, inflexible models popular in the West from the 1940's to the early 80's.
All of these manufacturers sofar have been anxious to gain and employ new and better designs and manufacturing techniques. Therefore our first goal has been to create a network for the free flow of information between wheelchair builders throughout the world.

The lightweight aluminum models that the Westerners now ride are of interest to Third World manufacturers, but the cost of the high-tech tools and materials to make these chairs is far too high.

We have attempted to put as much high-tech wheelchair design as possible into a form that can be built in the Third World, and then to seek out expert mechanics who can adapt and improve our designs the chairs for manufacture in each country. The result sofar is a combination of ideas that is giving useful innovations back to the Western world.

MORE THAN A TECHNICAL PROBLEM

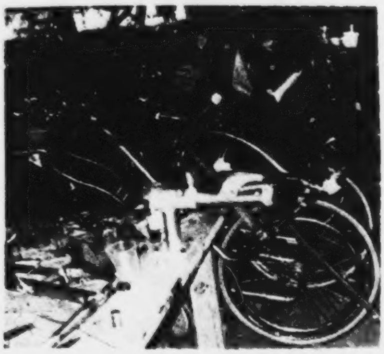
Even when good low-cost wheelchairs have become available, very few people in most countries have been able to buy them. Because there are few government programs to assist in the re-integration of disabled people, most of our customers have been from the wealthier families. The Disability Rights movement is gaining significant political strength in some countries, and change is coming quickly in school and job discrimination. But lacking the most basic transportation, many disabled people are still left out.

India may demonstrate that change is more possible - and practical - than we had thought. The Indian Government has provided hand powered tricycles - heavy duty outdoor models - to thousands of its citizens. They are ready and willing to provide wheelchairs, We have been told, provided good, dependable and usable chairs can be made for close to the $70. price of a tricycle. If this chair can be made - and it appears possible - India's mobility disabled population may enjoy the biggest and fastest revolution in their lifestyle that the world has ever seen.

NICARAGUA, 1980

We first tried out low-cost wheelchair making in Nicaragua, where a wheelchair shop was established by a new organization of disabled people in 1980. In the process of building our first chairs from scratch, it became obvious that the Norteamericanos had more to learn than the Nicaraguans. None of the special parts that wheelchair companies buy ready-made in the U. S. were available; the production techniques we took for granted were inappropriate in Nicaragua and my favorite designs could not be built.

The managers of the Nicaraguan shop were at times unwilling and at times unable to invest in enough raw materials to keep production operating smoothly; they were constantly running out of necessary supplies. We had to revise our methods to work with very little operating capital. All of the parts of our chair had to be built in small batches instead of in serial production because there were rarely enough materials to make more than a few of each part at a time. Our jigs and fixtures, in turn, had to be designed for very fast setup. With such short production runs, and with no space in the small shop to leave jigs set up, different jigs had to be set up several times a day.



Wilfred Senaviratna, Blacksmith, Sri Lanka

STANDARD COMPONENTS WERE NOT AVAILABLE

One assumption we made initially was that some materials and parts could be imported. This was not possible because the cost was too high. We had to find ways to make our own footplates, front wheels, caster forks and hubs. Furthermore these parts could not be factory-made as in the U.S. out of cast aluminum or press formed sheet metal; replacement parts would not be available (as is often the case in the U.S.) outside the big cities. All these parts were eventually replaced with parts that can be locally fabricated by a blacksmith.

Because Nicaraguan wheelchairs are used on rough roads and because replacement parts were hard to get, it was necessary to make the chairs as dependable as possible. Each chair must be strong enough to withstand the substantial impact forces that occur when the chair hits curbs at high velocity or is thrown on the roof of a bus. All the points where chairs normally fail were analyzed, redesigned, subjected to destructive testing, and revised until breakdown in the field became a very rare occurrance.

The axles on many Third World wheelchairs had been taken from standard bicycles, but bicycle axles are too thin for active wheelchair use and continually bend or break. We chose to use larger 5/8" bolts as-axles, and redesigned the hub of the wheel to fit this axle.

Because there is no guarantee that regular maintenance will be performed, we felt it was necessary to keep the maintenance requirements to a minimum. Some especially long lasting, low maintenance components were needed, despite their higher cost. We decided, for example, to use precision sealed bearings, even though unsealed bearings cost less, because the sealed bearings did not need adjustment, cleaning, or oiling and because they lasted so long that we virtually never needed to replace them.

PERFORMANCE REQUIREMENTS: LOOKS DON'T COME LAST

Wheelchair riders throughout the world are concerned about the appearance of their chair; most still covet an outdated, chrome-plated hospital style chair. Our first chairs were simple, strong, and, to some people, ugly. We quickly learned that the most efficient, low-cost chair won't be used if it doesn't appeal to the consumer. Since then we have paid much more attention to the appearance of our chairs, and have had some success in making them look good without raising the price.

Along with being dependable and looking good, a good chair must be easy to operate. The chair must be compact enough to slip through narrow doorways, yet still be stable outdoors on rough terrain. It should maneuver quickly and smoothly, being as much at home on the basketball court as on village roads.

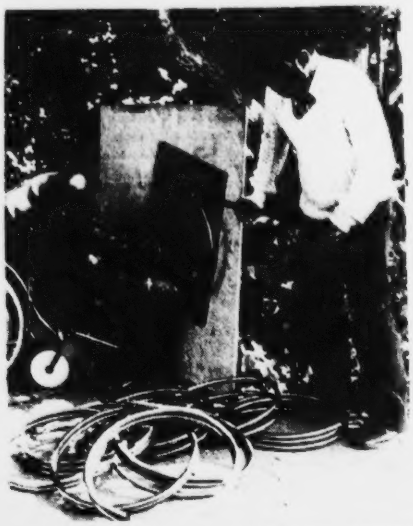
Oerestes Quispe, Arequipa, Peru

In particular the chair should be lighter than a customary wheelchair since it will be pushed and lifted under difficult conditions. At first it appeared to be impossible to lighten the chair while switching from high-tech components to parts that could be made from mild steel by a blacksmith. After reshaping the frame to reduce the stresses on it and combining the functions of several structural parts, our chair eventually weighed 25% less than a customary wheelchair (The current weight is 35 lbs ¡16 kg¿ when the chair is made of mild steel; 26 lbs ¡12 kg¿ when made of chromoly tubing with aluminum wheelrims)

We have chosen balloon tires for the rear of the chair and wide wheels for the front so that the chair can travel over soft ground. The armrests follow the curve of the wheels, and the footrests fold close to the frame of the chair, to allow the rider as easy a transfer into and out of the wheelchair as possible.

THE INTERNATIONAL NETWORK OF WHEELCHAIR BUILDERS

For the past five years, we have been helping groups in developing countries to set up shops to make and sell our particular wheelchair design, "El Torbellino" (in English, the Whirlwind). Currently close over 80 mechanics have been trained, and efforts to build the chair are underway at 20 workshops in 12 countries. We have made contact with well over 100 other wheelchair builders, and shared technology with all of them.



Patrick Gumete and Donovan Thame, Zimbabwe

A newsletter, Wheelchair Makers' Exchange, has been established to pass on new developments. Descriptions of new designs and fabrication methods are being sought from all participating groups for publication free of charge. To be placed on ATIL's mailing list, write to:

Appropriate Technology for Independent Living
6505 Farallon Way
Oakland, California 94611
USA

SUCCESS RATES AMONG WHEELCHAIR MAKERS

Our experience with the variety of organizations that have attempted to establish themselves as successful enterprises has taught us to expect some groups to do better than others. While there have been striking successes among all types of organizations, the failure of certain groups has led us to better appreciate how difficult it can be to establish and maintain a successful wheelchair business.

Out of nine enterprises founded by existing small businesses, six are continuing to build wheelchairs. The founders contributed their business contacts and skills to this success, and thus have had less difficulty any other groups. Among the most successful have been companies already established as makers of older style wheelchairs. On the other hand, some small business owners have not understood wheelchair use well, and have tended to stray from the goals of high quality and low price.

Out of 13 rehabilitation institutions that have attempted to establish production shops, only three are now producing chairs on a regular basis. Some of the rehabilitation professionals have found it difficult to allow their disabled workers, even those few disabled workers who were placed in management positions, to make business and design decisions. Several of the top graduates of our wheelchair-building courses have been discouraged by this treatment and have gone on to better employment. The rehabilitation institutions, having lost their most competent technical leadership, have as yet not recovered.

Of those wheelchair shops that were managed and/or owned by disabled persons, seven out of nine have done well. We have found that skillful disabled managers and workers have the most incentive for keeping the quality high, the price low, and for marketing directly to disabled consumers. Because most of the disabled people we have worked with have had limited accounting or management experience, they have needed some assistance from the business community in order to begin operations.

RURAL REHABILITATION: ON THE ROAD AGAIN

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ABSTRACT

Although there are similar rehabilitation needs in rural regions and in urban areas, it has been difficult to attract and keep qualified rehabilitation personnel. Furthermore, the expenses of establishing and maintaining a fully equipped rehabilitation center is prohibitive; oftentimes it is difficult finding a centralized location to serve the population. This paper describes Community Services, a rehabilitation program providing services to individuals of all ages and disablities in southern Missouri and Illinois, is coordinated through the Program in Occupational Therapy, a component of Washington University in St. Louis.

INTRODUCTION

Two factors have directed the beginnings of nonhospital service delivery models located in community settings. One factor deals with the limitations of the direct services model. Traditionally health care professionals have been educated to provide direct services to individuals. However, there is growing evidence that service delivery is more effective and economically efficient when the parents or caregivers are involved as an integral part of prevention, early detection, and remedial programs (1).

The recognition of the need for early intervention is the second factor. Many health problems experienced by adults: the major causes of mortality, chronic diseases, long term disabilities, emotional and behavioral disorders, mental retardation, problems related to pregnancy,and other may have their origins in early childhood and are preventable or at least responsive to early intervention (2).

While a community based service model is ideal, a centralized location does not well serve a large geographical area. With a large number of health care professional positions remaining vacant because of the lack of qualified professionals to fill vacancies and the inability to pay competitive salaries, few local organizations have access to the necessary expertise.

BACKGROUND

Improvements in medical practice after the Civil War resulted in increasisng numbers of wounded men in World War I living and needing rehabilitation. The Program in Occupational Therapy at Washington University, originally the St. Louis School for Recreational and Occupational Therapy started in 1918, was one of the first five schools established to provide reconstruction aide training programs mandated by the Medical Department of the Army (3). Two types of reconstruction aides were authorized: physiotherapy aides and occupational therapy aides. Both types of aides were trained to provide rehabilitation services in Army hospitals.

In 1979 the Program in Occupational Therapy initiated a graduate program offering a concentration in community pediatrics. The graduate program and community concentration evolved from a Maternal and Child Health Grant funded through the then Department of Health, Education, and Welfare. This grant provided monies to prepare and train two occupational therapists at the graduate level per year in the areas of identification of children at risk; prevention; and education of agency staff, parents, children, teachers, and the general public (4).

In addition to the funds for two traineeships, the grant allocate seed money to start Community Services, a service provision program staffed by clinical educators to provide occupational therapy services to community agencies and laboratory experiences for the trainees. At one time 18 community organizations in the Illinois and Missouri areas were served by four full time equivalent employees; some clinical jobs were split with teaching duties. By 1984, the end of the grant cycle, ten individuals had completed the traineeships; seven of the ten provide services to community agencies today.

As part of an administrative change Community Services was moved from the Program in Occupational Therapy to the Irene Walter Johnson Institute of Rehabilitation, another component of Washington University, in 1984. At this time the therapists providing community services elected to continue serving all but one of the contracts privately.

By 1986 Community Services had eight contracts with community agencies. The emphasis shifted from pediatrics to incorporating the provision of services to individuals of all ages and disabilities. On December 1, 1986 another administrative change had occurred and Community Services was again placed under the auspices of the Program in Occupational Therapy. This transfer took place in order to provide cost effective services under a program with less expensive overhead and other indirect charges.

METHODS

Following the changes in 1984, when the program was transferred to the hospital and only one community contract remained, steps were taken to analyze the marketplace for providing services outside the hospital.

A major change had occurred in Medicare reimbursement: P.L. 98-21, the Socal Security Amendments of 1983, mandated the use of a prospective payment system utilizing DRGs (diagnostic related groups) for inpatient hospital costs (5) While stipulated services, including rehabilitation services, were exempt from the new reimbursement system, it was understood that ultimately the new regulations would govern all facilities that utilize federal funds.

The initial impact of the new system was a shift in the pattern of viewing health care delivery; particularly from the hospital's viewpoint. To remain financially stable, the hospital needed to broaden its market. The community was viewed as one method; many hospitals launched major advertisement campaigns over the media. Another marketing method used by the hospital was to view itself in terms of the product lines it produced, a device previously used in business, but considered distasteful in the health care arena.

The first step used in the analysis of the community was the examination of the role of service delivery within the community system and the factors influencing the system (6). The Systems Skills Assessment (7) and the Community Resource Assessment (8) were used in the second step to determine the need for community services in addition to those depleted by private practitioners in the area. The third step was the establishment of the product line: services.

RESULTS

Both direct and indirect services were identified as the product line. Specific direct services included evaluation, treatment planning, and intervention while education and consultation comprised indirect services. Those agencies without health care resources were targeted for inquiry and inservice demonstration.

Of the 16 facilities solicited, eight signed contracts. Six requested direct services on a part time basis and two chose consultation and education. All eight contracts have been renegotiated for a second and third year. Each contract is different and reflects the nature of the facility; e.g., the contract 200 miles away included not only mileage, but also a drive time charge.

In addition to providing therapists who travel to community agencies to work on the premises with equipment provided. There are three diagnostic teams who provide specialized services in the form of clinics. These clinics are available in the areas of augmentative communication, mobility and control, and computer applications.

The three units utilize a transdisciplinary approach. The augmentative communication unit is composed of a speech and language pathologist, occupational therapist, social worker, educator, and vendor; the mobility and control team has a physical therapist, occupational therapist, social worker, educator, and vendor; and computer applications group. is comprised of an occupational therapist, speech and language pathologist, social worker, educator, engineer, and programmer/analyst. Each group is able to schedule time and will travel to the agency requiring services.

CONCLUSION

This project is easily replicated as the basis for a private practice or a way to broaden the market of a hospital based rehabilitation program. The steps are relatively simple: the market must be analyzed, a needs assessment performed, and product line designed.

ACKNOWLEDGEMENTS

The first author, one of the last trainees funded by the Maternal and Child Health Grant, wishes to thank the Carol Niman, MS, OTR and the Program in Occupational Therapy for the traineeship opportunity. This work was supported by Judevine Center for Autism, Coleman Tricounty Rehabilitation Services, Mamie O. Stookey School, the St. Louis Public Schools, and the Program in Occupational Therapy at Washington University.

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BREAKING NEW GROUND'S MARK II CHAIRLIFT FOR AGRICULTURAL EQUIPMENT

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ABSTRACT

This paper describes the Mark II chairlift developed by the Breaking New Ground Project at Purdue University. The chairlift is designed to be installed on various agricultural tractors in order to allow farm operators with mobility impairments access to their tractor cabs. The lift described is now commercially available.

INTRODUCTION

The initial (Mark I) chairlift designed by Purdue, utilized an electric-motor-driven vertical screw to lift a pivoting arm carrying the chair seat. This unit was installed and tested on a Case 1290 tractor. Even though the concept worked, it was concluded that a simpler version could be made using an electromechanical ball-screw linear actuator, mounted diagonally in a parallelogram linkage to lift the chair. This improved design was identified as the Mark II (Figure 1).

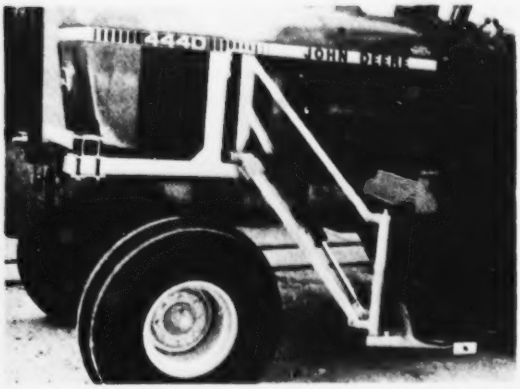

Figure 1. The Improved Mark II.

MARK II CHAIRLIFT

The Mark II Chairlift has been successfully installed on a Case 1290, Ford 4610 and John Deere 4440 tractors.

The improved Mark II design incorporates a swiveling seat arm (Figure 2), a padded bucket seat and an adjustable mounting frame (Figure 3) attached to the tractor front weight carrier bolts.

The swivel feature allows clearing the open cab door but still places the operator's feet on the door sill for transfer to the tractor seat. The outer vertical member of the parallelogram linkage is a tube which serves as a bearing to support the vertical stem of an arm carrying the bucket seat. The swivel feature also allows positioning the seat for access from a truck and for refueling.

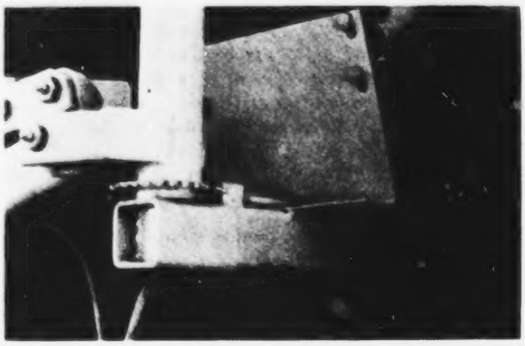

Figure 2. Mark II's improved swiveling seat arm.

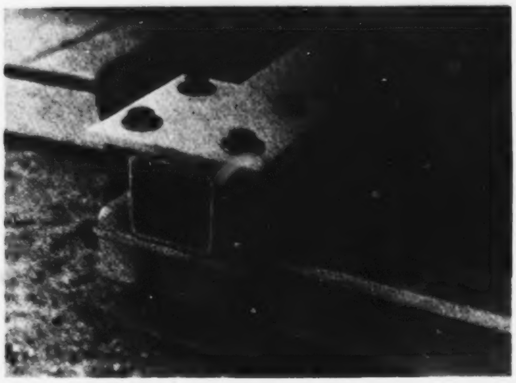

Figure 3. Adjustable mounting for the improved Mark II.

The lift is controlled by three adjacent pushbuttons mounted under the righthand edge of the bucket seat; one for lift, one to lower and one to release the swivel lock. This allows the lift to be controlled by the fingers of one hand while the swivel position can be controlled by the free hand grasping the tractor. Duplicate control buttons are provided on the tractor dash.

The actuator has a 12" stroke and is rated at 1500 lb. of force. Its retracted length is 19.9" between the two mounting pins. It has a 12 volt DC motor drawing up to 15 amperes which drives a screw by means of a sealed permanently-lubricated gear train. The screw passes through a recirculating ball nut attached to a stainless steel tube, which extends out through a grease and dust seal. The sealed actuator contains internal mechanical stops at each end of the stroke with a slip clutch to prevent overloads.

The parallelogram linkage is supported by a vertical 3" square tube welded to a horizontal 3" square tube extending forward. This tube is clamped to a 3" square cross tube with welded bolting arms which are interposed between the tractor and the front weight carrier. The rear of the frame is also supported by contact with an arm attached to the tractor side frame. The adjustable construction allows the linkage support to be moved in and out to clear the tractor, and fore and aft for optimum position of the chair for cab entry. Thus one basic chairlift can be adapted to a wide variety of tractors by changing only the cross tube bolting arms.

The lower link of the parallelogram is a 2" square tube to provide stability against twisting loads. The upper link is loaded only in tension and is made of a pair of 1/4 x 1-1/2" bars welded together. Needle bearings are used at the ends of the lower link and the actuator links.

The parallelogram linkage magnifies the actuator's 12" stroke to give 51" of lift with 300 lb. lift capacity. The entire assembly is mounted on vertical pivots. The linkage is automatically swung in toward the tractor as it lifts by a swing link with ball joint ends which connects the frame to the lower link near its inner end. The swing link length can be adjusted to obtain the desired horizontal stopping position at the top of the lift.

MOUNTING AND DISMOUNTING PROCEDURE

To mount:

1. Remove the left wheelchair arm and slide over to the lift seat.
2. Raise the seat high enough to unlatch the cab door and swing it open, lowering as required for clearance.
3. Swivel the seat as required to clear the cab door as the seat raises and swings in to its top position (Figure 4).
4. Transfer to the tractor seat using handgrips and/or shelf supports.
5. Swivel and/or lower the seat as required to close the cab door and allow maximum visibility.

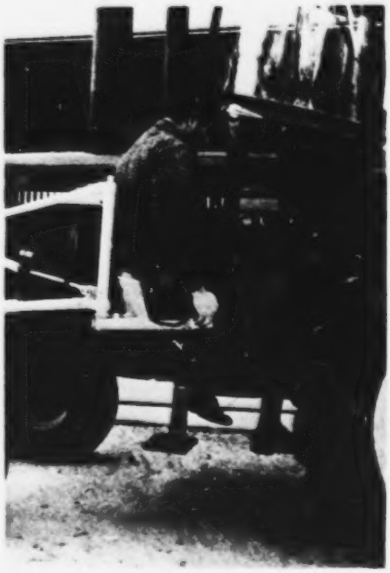

Figure 4. Chairlift in use.

To dismount:

1. Open the cab door and position the seat for exit access.
2. Transfer from the tractor seat to the lift seat.
3. Lower and swivel the seat to down position, closing the cab door on the way down.
4. Transfer to the wheelchair.

COMMERCIALLY AVAILABILITY

For information on commercial availability of the improved Mark II chairlift, write or call Round Grove Machine Corporation, 345 Burnett Road, West Lafayette, IN 47906, (317)423-4192.

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AGRICULTURAL WORKSITE ASSESSMENT

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Purdue University

ABSTRACT

During the past few years the authors have participated in numerous agricultural worksite assessments for farmers and farm workers affected by physical disabilities. The experiences gained have been translated into a formal Agricultural Worksite Assessment Tool. This paper will discuss the tool and its potential applications.

INTRODUCTION

Health care and rehabilitation professionals have used various assessment tools for a number of years. The purpose of an assessment tool is to obtain information on the health care and rehabilitation needs of an individual, and to assist in the development of a plan for meeting these needs. Farm families affected by physical disabilities are often found to have unique needs that are seldom uncovered through the use of current assessment tools. In addition, many health care/rehabilitation professionals lack an understanding of the agricultural worksite. They are unsure as to what questions to ask or what services they could provide to allow a farmer/rancher with a specific disability to remain active in the farm operation. As a response to this need, the "Agricultural Worksite Assessment Tool for the Physically Disabled Farmer/Rancher" was developed. The assessment tool focuses only on the agricultural worksite and should be used in conjunction with a current comprehensive rehabilitation assessment tool which addresses independent living needs, dietician needs, financial assistance, medical management, disability adjustment counseling, and family counseling needs.

PURPOSE

The purpose of the "Agricultural Worksite Assessment Tool for the Physically Disabled Farmer/Rancher", is to provide the professional with a list of detailed questions to ask about the agricultural worksite. The answer to the questions will provide the user with many of the needed details as to why a particular farm task is difficult to perform; possible ideas on worksite modifications or task restructuring that could be done to overcome specific problems; and the identification of specific goals to increase independence and productivity.

The agricultural worksite assessment tool is divided into eight informational gathering areas, including:

I. Personal Data

II. General Farm/Ranch Data

III. General Farm/Ranch Accessibility

IV. Livestock Handling

V. Equipment and Machinery Use

VI. General Farm Maintenance

VII. Farm Management Activities

VIII. Additional Vocational Skills

IX. Establishing Primary Goals

To assist the professional in administering the assessment tool, a user's guide has been developed. This guide provides background information to help the user understand why specific questions are being asked and what worksite information is most important to obtain from the farmer/rancher.

The following is an excerpt from the user's guide which helps the professional through the section of the assessment tool dealing with agricultural equipment and machinery use.

Information requested in assessment tool:

> List primary self-propelled machines in use (tractors, combines, skid-loaders and other self-propelled units).

Information provided in user's guide:

> Farmers use a wide variety of makes and models of self-propelled equipment. It is not unusual that a farm/ranch has five or more tractors, combines and other self-propelled machines. On some farms/ranches, the farmer/rancher may spend long hours operating this equipment and in most cases being able to operate the equipment, at least some of the time, is almost essential to successful continuation of farming.
>
> It is important to know which of these self-propelled machines the farmer/rancher uses most frequently. If modifications are made, they should be completed on the newer and more frequently used machines.
>
> Knowing whether or not the equipment is cab equipped helps if modifications are made. For individuals with respiratory impairments and spinal cord injuries, a modern pressurized cab is important in

controlling environmental conditions. Individuals with temperature sensitivity can benefit from such features as cab heater and air conditioner. Two-way radios are strongly recommended for individuals with mobility impairments to ensure that they can obtain assistance when needed. On larger farm operations, radios are no longer considered accessories but essential and cost cutting management tools.

Information requested in assessment tool:

Describe the difficulties that the farmer/rancher has in independently mounting and dismounting frequently used equipment. Explain current methods used.

Information provided in user's guide:

During the assessment process, it is important to gather as much information as possible concerning the specific problems in accessing the most essential and most frequently used pieces of agricultural equipment. Photographs are encouraged of the equipment that presents the most serious problems and that might be considered for modifications.

For less severe mobility limitations, the solutions might be as simple as additional hand holds, an extra step, placing steps closer together, or even an alternative climbing method. For individuals with severe walking limitations, platform lifts or chairlifts have been designed which can be mounted to the tractor or combine which allow the operator to access the operator's platform without climbing. When trying to identify a suitable solution, knowing the equipment make and model, along with the current difficulties of operation, is important.

During your assessment, you might observe the farmer/rancher involved in what appears to be a dangerous task. It probably is. Potential hazards should be noted as a problem and be considered a high priority when modifications are considered.

Alternative methods of accomplishing a task which is unsafe is not an appropriate application of rehabilitation technology. Remember, nearly 75 percent of all serious farm-related injuries result from mishaps with agricultural equipment.

The Breaking New Ground Project at Purdue University has developed a variety of resource information that would be extremely helpful in considering various approaches to accessing agricultural equipment.

SUMMARY

The authors hope that the "Agricultural Worksite Assessment Tool for the Physically Disabled Farmer/Rancher" will become another useful tool to improve the efficiency and effectiveness of the rural rehabilitation professional. We encourage that the tool be used in conjunction with the Breaking New Ground resource manual, "Agricultural Tools, Equipment, Machinery and Buildings for Farmers/Ranchers with Physical Handicaps" to identify modifications for specific disabilities. Local resource people should also be utilized to obtain ideas for overcoming specific barriers as well as for assistance in designing and fabricating adaptive equipment and modifications.

For additional information concerning the agricultural worksite assessment tool and other resources relating to rural rehabilitation technology, contact Breaking New Ground, Department of Agricultural Engineering, Purdue University, West Lafayette, Indiana 47907.

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Special Interest Group 13

Robotics

Chair: Larry Leifer, Ph.D.

THE USE OF ROBOTIC MANIPULATORS AS COGNITIVE AND PHYSICAL PROSTHETIC AIDS

Richard D. Howell
Suzanne K. Damarin
Paul E. Post
The Ohio State University

ABSTRACT

Recent advances in the research, development and use of robot manipulators show great promise as functional prosthetic aids for the disabled individual with neuromuscular disorders. These devices promise to one day provide a greater degree of personal independence and vocational access for disabled persons than has ever been possible. However, an unexplored dimension of present research and development efforts involves the educational and cognitive effects of robotic use and the training methodologies used to teach students how to use them. This study examines specific issues related to the training and cognitive effects associated with the use of robotic manipulators by disabled students. The investigation focuses on a comparison of instructional strategies and on visual and spatial skills associated with manipulator use.

INTRODUCTION

Research being conducted at the Ohio State University investigates the use of robotic manipulators by severely disabled children for educational and recreational applications. Of particular interest to the researchers are the educational and cognitive implications of using robots in structured and unstructured environments. The main objectives of this research project are:

1. To develop functional living and working skills using the robotic manipulator (the Rhino XR-2 manipulator).
2. To discover the cognitive demands and effects associated with using robotic manipulators.
3. To design and develop effective training sequences for instructing students in the use of robotic manipulators.
4. To discover the relative costs and problems associated with use of "off-the-shelf" robotic technologies for present day applications.

BACKGROUND

The use of robotic devices as prosthetic physical aids has already been shown to be technologically feasible and functionally effective (1,2,3). Progress in this area promises to generate a variety of electromechanical devices for the enhancement of human abilities which have been damaged or are non-functional. Although the use of robots in the field of rehabilitation engineering has demonstrated the prosthetic value of the devices (3,4,5), their potential in the comprehensive rehabilitation plan of physically handicapped individuals has yet to be fully realized. It appears that the prosthetic advantage afforded by robotic devices applies to certain physically handicapping conditions including persons with spinal cord injuries (4,5); with disabled geriatric patients (6). And yet, there are many barriers hampering the adequate investigation of robotic applications in special education, including cost, hardware adaptation, and software design and development (7). In addition, there has been no specification of effective training methodologies in the work that has been done up to this time. Much of the work to date has focused primarily on the development of the physical parameters of robots, without acknowledgment of the significant cognitive impacts that probably accompany the manipulative prosthetic advantages. The cognitive impact of robotic use by the handicapped, especially by the young physically handicapped student, is an area which shows great promise but has received little research and development attention. With these considerations in mind, it is possible that the use of robotic devices may not only act as physical prosthetics, but also as cognitive prosthetic devices.

While the lack of such sensory input at an early age may have deleterious effects on cognitive growth, it is possible that the intrinsic qualities of flexibility and resilience within the developing human utilize whatever skills and abilities are present in order to facilitate continued cognitive growth. Some support is given for this position by Flavell (8) who posits that, "If the usual, typical developmental route is blocked, the child may find an unusual, atypical one that somehow gets him to at least approximately the same cognitive destination" (p. 238). By using the robot as a mechanical sensor and manipulator the child may be able to experience important aspects of the world and grow cognitively from those experiences, thus expanding the definition and applications of prosthetic devices. It may be that the use of a robotic device would act as a linkage between the handicapped child and the external world, with the child growing cognitively from the experience. In the robotic environment, the handicapped child moves the device to designated locations, uses it to speak via speech synthesis, grasps and interacts in a real, physical sense with a world that was formerly completely out of reach.

The development of cognitive and physical abilities are so closely interrelated that physical exploration of the environment and manipulation of its elements contribute to the formation of mental skills such as those associated with spatial awareness. These skills help children to develop a sense of control over their environment as they gradually move from an egocentric perspective (where one views the world solely from a personal orientation) to an allocentric perspective (where one views the world from an orientation other than their own). Through creative play, direct experimentation, and exploration activities the handicapped child can use the robot to develop strategies for interacting with their environments. These interactions may even change the basic knowledge-gathering and environment-structuring capabilities and strategies of the child. In addition, the child is required to employ directional concepts in order to operate the robot, thus enabling her/him to learn more about the outside world as she/he grows in cognitive complexity towards more formal operational analytical capabilities.

METHODS

Previous research using robotic devices with the disabled have led our research team to view the conceptualization and design of instructional treatments and measures as a major part of its work. Working from an instructional design model developed by Damarin (9), the team begins each phase of the investigation with analyses of the content of instruction. These analyses go beyond traditional task analysis in that they include a careful delineation of the broader cognitive and affective context in which the task resides. The content and analysis process includes: (1) consideration of the nature of the subject populations, (2) an analysis of the physical control and positioning needs of the subject, and (3) the generation of viable research hypotheses. This information leads to the development of the training sequence; and finally, to the development of the software and the specific hardware specifications required for the subjects. This approach also provides an initial foundation upon which to begin the training and is evaluated formatively throughout the course of the study in order to remain responsive to any inappropriate aspects of the hardware, software, or training methods.

The hardware required for use in this project includes an adaptive input device, the computer system, and the robotic manipulator. The adaptive input device was designed to meet a variety of control deficits experienced by orthopedically handicapped users. The Prentke-Romich 5-slot switch was chosen as the adaptive input device for this project. The computer used is a standard Apple IIe with a color monitor. The robotic arm used in the current research at The Ohio State University is the Rhino XR-2 which has 5 degrees of freedom, utilizing servo-control motors. The arm is attached to a workstation that is designed to provide a flexible working environment and to ensure that the user is safe from being injured by the manipulator.

Population. The students selected to work with the robotic manipulator exhibit mild-to-severe orthopedically handicapping conditions that severely limit their ability to operate on the environment. The four students selected for this study include two diagnosed as cerebral palsied, one with muscular dystrophy and one with a severe head trauma. Each student is exposed to the robotic manipulator and training methodology twice a week for 30 minute sessions. The training is presently in its second month with a total of four months training being projected for purposes of the research project.

Training sequence. An analysis of content involved in gaining mastery of a robotic arm reveals that the subject needs to acquire skill through a series of levels and that these levels are likely to require the application of increasingly complex strategies and diverse cognitive abilities. The skills gained at each level must be mastered but not overlearned; overlearning may lead to fixation at a level of control which is relatively primitive with respect to the desired flexibility of user knowledge and control. This is especially important since the primary objective of training must be the ability to use the robot effectively in unstructured tasks and environments. The following experimental training sequence being used in our research is attentive to these issues:

LEVEL I: DEMONSTRATION. To demonstrate the functionality of the robotic arm in a context that is reinforcing to the student and to establish a relationship between the input device, the robotic manipulator, the menu and graphic displays on the monitor.

LEVEL II. BEGINNING CONTROL. Students will operate the robotic arm to perform several well-defined tasks in which help and feedback are provided by the computer and instructor.

LEVEL III: INTERACTIVE CONTROL. Students will interact with the robotic arm in an unstructured environment and be given progressively greater control over the different types of movements.

LEVEL IV: PROGRAMMING THE MANIPULATOR. Students will create and save procedures for using the robotic arm in functional and recreational tasks within unstructured environments.

Evaluation. Student progress with the robot is being evaluated in both a formative and summative fashion that: (1) allows for continuous checks on the progress and quality of the training procedures; (2) provides accurate measurement of cognitive goals; and (3) evaluates the accessibility and utility of the equipment. A proposed hierarchy of visual-spatial skill development is being evaluated as a part of the 'cognitive impacts' research agenda in this project. The hierarchy involves progressively complex skill development beginning at the level of visual perception, moving to visual-spatial awareness, spatial transformation, and finally to visual mental imagery development. This specific project only seeks to investigate phenomena associated with visual perception and visual-spatial awareness skills.

In addition, much time and energy must also be directed at the adaptation of the data gathering instruments and consideration must be given to the implications of changes in the reliability and validity of the evaluative instruments. The wide range of communication problems evidenced by many physically handicapped children provides an important challenge to future researchers in this area. Accessing and correctly interpreting relevant feedback from the student is critical to the understanding of the cognitive demands and impacts associated with using robotic devices.

RESULTS

Since the study is ongoing at this time, there are no results to report. Data is being taken in two domains: (1) performance based information regarding the effectiveness (number of correct moves) and the efficiency (amount of time to complete the task): and (2) cognitive impacts on visual-spatial skill development using motor-free tests of visual perception and an adapted Frosting Test of Visual Perception.

DISCUSSION

The complex interactional nature of the instructional robotics environment is composed of the students, each of whom brings a unique set of training needs to the environment, adaptive devices, computer hardware and software, and the robotic device. This complexity can form a primary barrier to widespread research and developmental efforts. Other issues that have already surfaced from our investigation which warrant comment are: cost, technical expertise, hardware limitations and community/school support for high-technology research projects. Taken together, these issues form significant, but not insurmountable barriers to the continued research and development efforts of robotic systems with handicapped children.

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EXPERIMENTAL STUDY OF A NATURAL-LANGUAGE INTERFACE TO AN INSTRUCTABLE ROBOTIC AID FOR THE SEVERELY DISABLED

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ABSTRACT

Disabled persons should be able to use robots to perform manipulations associated with simple activities of everyday living. The human/machine interface is of particular importance in such situations: it provides a way for the operator to command and instruct the robot, producing the correct real-time behavior and augmenting the store of the robot's procedural knowledge. We are in the process of developing an Instructable Robot System that will serve as a test bed for further studies on human-robot interactions. The goal is to build a practical system that will accept verbal commands and function efficiently in a homelike environment. We report initial results on an interactive robot that is to serve as a rehabilitative aid for quadriplegics. The robot is a nine degree-of-freedom manipulation system consisting of a robotic arm mounted on an omnidirectional mobile base. We have implemented a control architecture that allows a user to direct the motions of the mobile base by means of commands expressed as colloquial English sentences.

INTRODUCTION

The present work on robot instructability is based on an ongoing effort to apply modern manipulation technology to serve the needs of the handicapped [1]. The Stanford/VA Robotic Aid is a mobile manipulation system that is being developed to assist severely disabled persons (quadriplegics) in performing simple activities of everyday living in a homelike, unstructured environment. It consists of two major components: a nine degree-of-freedom manipulator and a stationary control console [2].

In clinical applications, the Robotic Aid has been used as a voice-controlled telemanipulator. To perform a task, a user gives a series of discrete, explicit motion commands, each corresponding to a degree of freedom of the robot, such as: *"Forward!"*, *"Left!"*, *"North!"*, *"Down!"*. The direction commands have to be qualified: the utterance *"Left!"*, for example, can refer to a rotation or a translation of the arm or of the mobile base, in any one of several coordinate systems. Furthermore, the command can be interpreted as an incremental motion or as a continuous velocity. A variety of qualifier commands are available to define the context of the specified directions. Experienced users of the Robotic Aid have achieved a considerable degree of skill: preparing and serving food, operating appliances, and performing various personal hygiene tasks. To an extent, however, users of the device have experienced frustration and dissatisfaction due to the unnatural character of the commands. The present work was undertaken in the belief that the Robotic Aid will be easier to use when the formalized command structure is replaced by a set of procedures which allow the user to issue commands in simple colloquial English.

SYSTEM ARCHITECTURE

In the work presented here, only the motions of the Robotic Aid's omnidirectional motion base have been considered, i.e., the six degrees of freedom of the arm and gripper have been ignored. The goal has been to develop some basic software tools for commanding the robot's motions in an enclosed room containing a few objects such as tables, chairs, and rugs. Given these goals and restrictions, the following are intentions that an operator might wish to communicate to the robot through the use of natural-language commands: that the robot go to a given region of the room; that the robot move in a given direction; that the robot avoid a given region; that the robot stay within a given region; that the robot follow a given path; that the robot stop doing whatever it is doing at that time; that the robot perform any specific motion at slower than (or faster than) normal speed; that the robot speed up; that the robot slow down; that the robot pursue two goals simultaneously (the goals are not necessarily achieved simultaneously); that the robot pursue one goal after another has been achieved; that the robot pursue a goal until a given condition is met (the pursuit of the goal will be interrupted); that the robot repeatedly pursue a goal until a given condition is met; that the robot pursue a goal if (or when or whenever) a certain condition is met. The conditions the robot must detect are: that a given distance has been traversed; that a given time has elapsed; that the robot is beyond one region relative to another; that the robot's bumpers are hit; and that the robot is in a certain region. The robot's software architecture was designed to allow commands expressing these intentions to be interpreted.

The interpretation of even the simplest English commands to a robot must take place in a contextual framework: one that specifies the perceptual, cognitive and motor functions of the robot, as well as an abstracted model of the external world (the robot's operating environment) which can be used to resolve references to such entities as objects, trajectories, and directions.

In the present work, the environmental model takes the form of a two-dimesional map with objects represented by polygons (Figure 1). Admittedly, such a highly simplified scheme bears little resemblance to the elaborate cognitive models of reality that are used in normal human discourse. In particular, the polygonal model is given *a priori* and does not contain any perceptual elements: there is no "polygon sensor" on board the mobile robot. The adopted model should be viewed as a temporary device that establishes a context for the more significant developments in system design, language processing, and real-time control.

Language processing provides an interface between the user and the robot. The robot is characterized by four kinds of behavior: 1) it can move about the room in a variety of generic ways; 2) it can monitor its internal state and its state with respect to the environment; 3) it can resolve certain references to its surroundings; 4) it can execute motion sequences within certain temporal and logical constraints. Specifically, these behavior modes are implemented in the following building blocks of the robot's software architecture: **MOTION ROUTINES**, **TEST ROUTINES**, **REGION ROUTINES** and **CONTROL STRUCTURES**.

MOTION ROUTINES are simple goal-oriented algorithms that can generate or change motion. Seven of these are currently supported: `Stop`, `Pause`, `Resume`, `Piloting` (moving in a specified direction), `RegionSeeking` (translating towards, or away from, known objects or regions of space), `Orienting` (rotating with respect to objects or regions) and `Repelling` (moving around obstacles).

TEST ROUTINES (or simply **TESTS**) are also simple run-time routines. They do not affect the motion directly, but return a boolean result. Six **TESTS** are currently implemented: `RobotInRegion?` (is the robot in a specified region of space?), `Facing?` (is the robot pointing at, or away from, a specified region?), `TimeElapsed?`, `DistanceCovered?`, `AngleCovered?` (has a specified time, translation, or rotation increment elapsed?) and `BumpersHit?` (has the robot's segmented bumper system hit anything?). Any **TEST**, along with its arguments, can be invoked in one of two modes: *IF* and *WHEN*. In *IF* mode, the computation is performed only once and the result (TRUE or FALSE) is returned immediately. In *WHEN* mode, the calculation associated with the **TEST** is repeated until TRUE is obtained. Some of the **MOTION ROUTINES** have implicit termination **TESTS**, invoked automatically whenever the **MOTION ROUTINE** is activated.

REGION ROUTINES operate on the robot's two-dimesional world model. Real-life objects are modeled as polygons ("regions"). In addition to named objects (*window*, for instance, names the window, *chair*, the chair, etc.), regions are also used to represent areas defined with respect to objects, as demanded by natural-language expressions such as *within six feet of the stairs*, *at least two feet to the right of the table*, and *this side of the chair*. These regions can be computed relative to any one of four coordinate systems: the fixed room system; one centered on the robot; one centered on the speaker; and one embedded in an object, such as a chair, that has an intrinsic orientation.

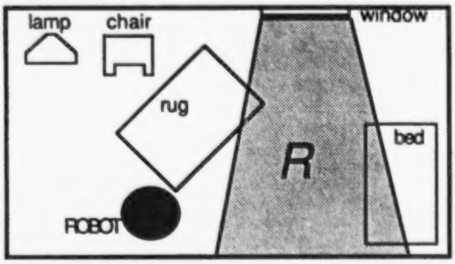


Figure 1: Two-dimensional map containing objects that are known to the robot *a priori*. The shaded area R represents the output of a **REGION REGION** invoked with the argument *in front of the window*.

CONTROL STRUCTURES embody the logical and temporal constraints imposed by the command. There are seven basic forms which may be combined recursively to describe complex behavior sequences:

DO(B [until x])
This form results in the execution of **MOTION ROUTINE** B, to be terminated as soon as **TEST** x returns the value TRUE. Because some **MOTION ROUTINES** have implicit termination **TESTS**, the until clause is optional.

SEQ($S_1 \ldots S_n$)
This form results in the sequential execution of daughter **STRUCTURES** $S_1 \ldots S_n$, each of the which may be of type DO, SEQ, PAR, IF, WHEN, WHENEVER or REPEAT. Language processing often produces the form SEQ(S), which simply denotes the execution of S.

PAR($S_1 \ldots S_n$)
This form denotes simultaneous execution of $S_1 \ldots S_n$.

IF(x then S_1 [else S_2])
This form denotes the execution of S_1 if the **TEST** x returns TRUE immediately, i.e. at the time that the IF **STRUCTURE** is first encountered by the robot's scheduling algorithm. Optionally, if x returns FALSE, S_2 is executed.

WHEN(x S)
This form is similar to (IF x S) except that **TEST** x need not be satisfied immediately: S's execution will await x being TRUE.

WHENEVER(x S)
This form results in the repetition of S each time x is true, with the provision that S must terminate before x is tested again. Because this form has no explicit termination condition, it is often combined with the DO form: DO(WHENEVER(x S) until y).

REPEAT(S until x)
This form results in the repetition of S until the condition x is TRUE. Each instance of S must terminate before another one can begin. The TEST x is evaluated whenever S terminates.

COMMAND INTERPRETATION

The Language Processor accepts a user command in the form of a colloquial English sentence. It produces an Interpreted Command which contains the following information:

- which of the generic robot **MOTION ROUTINES** are to be invoked.
- the temporal order of execution and the logical conditions under which the **MOTION ROUTINES** are activated and terminated, as expressed by **TESTS** and **CONTROL STRUCTURES**.
- the parameters of any polygonal regions that were referred to in the command, and are to be computed by the **REGION ROUTINE**.

In the following examples of Interpreted Commands, references to regions are left unresolved and implicit termination **TESTS** are not shown:

Go to the desk.

```
SEQ(RegionSeeking(<the region around the desk>))
```

Then go on over to the telephone when the bumpers are hit.

```
WHEN(BumpersHit?, SEQ(RegionSeeking(<the region
                               around the telephone>)))
```

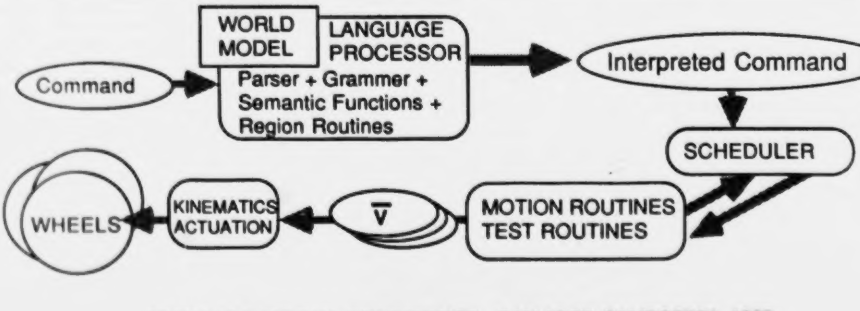
Slowly move backwards to within one inch of the stairs.

```
SEQ(DO(PAR( Piloting(Shift,Backward),
            RegionSeeking(<the region one inch
                               around the stairs>)),
      RobotInRegion?(<the region one inch around
                                   the stairs>)))
```

Go north west for three feet then face the chair.

```
SEQ(SEQ(DO(PAR(Piloting(Shift,North),
               Piloting(Shift,West)),
          DistanceCovered?(36 inches))),
     SEQ(Orienting(<the region around the chair>)))
```

An Interpreted Command is built up as follows. Individual words denote calls to robot **ROUTINES** and **CONTROL STRUCTURES**. These calls may be partially or fully specified. A call is fully specified when a **ROUTINE** (motion, test, or region) is named or a **STRUCTURE** is named and values are given to all its arguments. A partially specified call leaves undefined either the **ROUTINE** or **STRUCTURE** or an argument value. The process governing the synthesis of lexical calls (full or partial) to form an Interpreted Command, one that specifies robot action, is the semantic tree [3] [4]. This tree is



generated from rules of semantic composition (called semantic functions) that are attached to the phrase-structure rules of the grammar. While the the current implementation uses a context-free grammar, semantic trees require no particular grammar or parsing method. The concept of a semantic tree does fit very well, however, with the recent developments in augmented phrase-structure grammars that have led to the theory of lexical-functional grammars and to the unification-based grammar formalisms such as D-PATR [5] [6]. The grammar presently in use for the Robotic Aid was developed using the D-PATR system available on the XEROX 1108 Workstations. A COMMON LISP version of the parser, known as CPATR, is in use in the robot system. The reader is referred to [7] for a detailed discussion of the language processing.

IMPLEMENTATION

The mobile robot consists of a six degree-of-freedom Unimation PUMA 260 robotic arm, equipped with a simple gripper and mounted on a unique three-wheeled motion base. The 12-inch diameter wheels of the base are located at the vertices of an equilateral triangle with 17.3-inch sides. The circumference of each wheel consists of 20 free-wheeling rollers which allow the wheel to move in a direction parallel to its axis of rotation. An onboard processor generates position commands to the wheel controllers at a rate of 15 Hz. By choosing a set of three rotational wheel velocities, any combination of translations and rotations can be achieved.

The onboard computer is a Digital Equipment Corporation LSI 11/73. The motion computation routines were written in MicroPower PASCAL, a dialect of PASCAL that explicitly supports a high level of multi-process concurrence on a single CPU. This is achieved through a system of dynamic priority assignments and inter-process synchronization and communication functions such as semaphores and mailboxes. In addition, multiple invocations of a given re-entrant process can run concurrently, each in its own priority and memory-mapping context. Typically, at any given time, a dozen processes are competing for access to the CPU, the exact number of processes depending on the specific command being executed. A MicroPower PASCAL kernel assigns access based on priority. Although this system has the desired flexibility, it requires that the individual routines be as simple as possible to reduce the overall CPU load. The kernel contributes an approximate CPU overhead of 20%, with additional processing time needed for boilerplate functions such as kinematic computations and communication with the Language Processor.

When an Interpreted Command is produced by the Language Processor, it is acquired by a program called the Scheduler which is in charge of activating **TESTS** and **MOTION ROUTINES** based on the content of the Interpreted Command. Typically, inspection of the Interpreted Command will result in invoking one or more **TESTS** and/or **MOTION ROUTINES**. This is done by sending a coded command (containing the identifier of the desired routine(s) and its arguments) to the robot. A utility routine on the robot maintains a variety of tables and other data structures that keep track of the state of the system which, at any instant, is defined by the currently executing set of **MOTION ROUTINES** and **TESTS**. The instantaneous state of the robot persists until one of the **TESTS** returns a value. Then, and only then, is the Scheduler reactivated. It examines the Interpreted Command to determine the appropriate response — usually the invocation or termination of other **MOTION ROUTINES** and/or **TESTS**.

The Language Processor and the Scheduler were implemented in COMMON LISP on a stationary Microvax II computer. The **MOTION ROUTINES** and **TESTS** (implemented as PASCAL procedures) run on the mobile robot's LSI 11/73. To guarantee smooth motion of the robot, these procedures are executed at a fixed rate of 15 Hz. Whenever the Scheduler activates or terminates a **MOTION ROUTINE** or **TEST**, a command packet is sent to the robot via the radio link, specifying the name of the routine and its arguments. The robot responds whenver a **TEST** returns TRUE (if it was invoked in *WHEN* mode) or TRUE/FALSE (if *IF* mode was selected).

During most instances of command execution, a number of **MOTION ROUTINES** execute concurrently. For example, in the case of the command *Move to the front of the desk while facing the window and avoiding the rug and the lamp*, four **MOTION ROUTINES** are active simultaneously: `RegionSeeking`(<the region in front of the desk>), `Orienting`(<the region around the window>), and two instances of `Repelling`: one with argument (<the region around the rug>), the other with argument <the region around the lamp>). Each **MOTION ROUTINE** contributes to the overall motion of the robot in the form of a three-dimensional (two translations and one rotation) velocity vector in one of two coordinate systems: the fixed room system (directions: north, south, east, west, turn clockwise, turn counterclockwise), and the moving base system (directions: forward, backward, left, right, turn left, turn right). As noted earlier, all process computations are iterated at 15 Hz.

ACKNOWLEDGEMENTS

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EVALUATION OF A TABLE TOP ROBOTIC AID FOR QUADRIPLEGICS

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ABSTRACT

The purpose of this study is to evaluate and demonstrate the use of a table top robotic arm to serve the needs of the severely physically disabled. It is the specific intent of the evaluation to yield improved design specifications while the technology is evolving. Robotic devices potentially increase functional independence for activities that otherwise require assistance from family or attendant. The robotic aid being evaluated is a Unimation PUMA 260 industrial arm, augmented by an IBM PC/AT. A specially designed workstation surrounding the stationary arm supplies materials needed to accomplish some of the vital activities of daily living, such as meal preparation, feeding, hygiene and grooming. High level quadriplegics (neurologic levels C3, C4, and C5) with no functional use of the arms or hands operate the robotic aid using voice commands to execute pre-programmed tasks. Subjective and objective measures of robotic aid/workstation performance and user satisfaction are obtained for each of several functional tasks.

INTRODUCTION AND BACKGROUND

With the advances of the computer age, robots are potentially a practical aid for the disabled population, including spinal cord injury, arthritis, and numerous other muscular and neurological disorders, encompassing hundreds of thousands of individuals in the United States alone [1,2]. The concept of use of robotics for providing the disabled increased functional independence is not new. However, there is little definitive data in the literature on specific tasks demonstrated to be of practical application [3,4], i.e., performed satisfactorily within a reasonable period of time for the user. Up to now, most measures of a robot's effectiveness in a health care setting have been subjective. Although qualitative information is important, for cost/benefit analysis of robots in this setting quantitative measures of the robot's utility must be obtained. This study focused on measuring and evaluating the problems of practicality and the aspects of a robotic aid that presently work and those that do not, with a problem solving orientation.

MATERIALS AND METHODS

The robotic aid being evaluated is a PUMA 260 stationary arm, manufactured by Unimation for use in an industrial setting. A workstation has been assembled, which houses all supplies accessible to the arm that are needed for functional tasks [5]. Surrounding the robot are the following: a computer terminal, a microwave oven, a refrigerator, disk drives, a two way speaker phone, an environmental control unit, and supplies for activities of daily living (i.e. hygiene and grooming, feeding), vocational and recreational activities (see Figure 1).

Five high quadriplegics (neurological levels C3-C4) with no arm or hand function were trained to use the robotic arm to complete the following pre-programmed tasks using voice commands (see Figure 2):

1. Wash face
2. Brush teeth
3. Feed with utensils
4. Prepare meals (microwave, refrigerator)
5. Shave the face
6. Operate two way speaker phone, lamp and radio

The introductory orientation session for naive subjects required less than one hour to train the voice for computer recognition and learn how to execute pre-programmed tasks. Each patient is then instructed to complete the tasks with no assistance other than set up of the computer program. Each task is evaluated by the following criteria: time to complete, subjective satisfaction by the client, and objective measurement of task completion (thoroughness, outcome, etc.). Objective rating by an independent observer measured the quality of performance of each task. Objective measurement differed by task.

RESULTS AND DISCUSSION

Data were compiled on each of several measures for each task outlined above. A total of five quadriplegics have evaluated the sysem to date. Overall, functional tasks were able to be completed satisfactorily within a reasonable time. Both positive and negative feedback are being obtained, and software is being revised continually to respond to feedback by users and observations by staff. More positive averaged responses were obtained on the post-test than the pre-test for the following characteristics of the system: sturdiness, safety, ease of use, obedience, value, and reliability. Negative

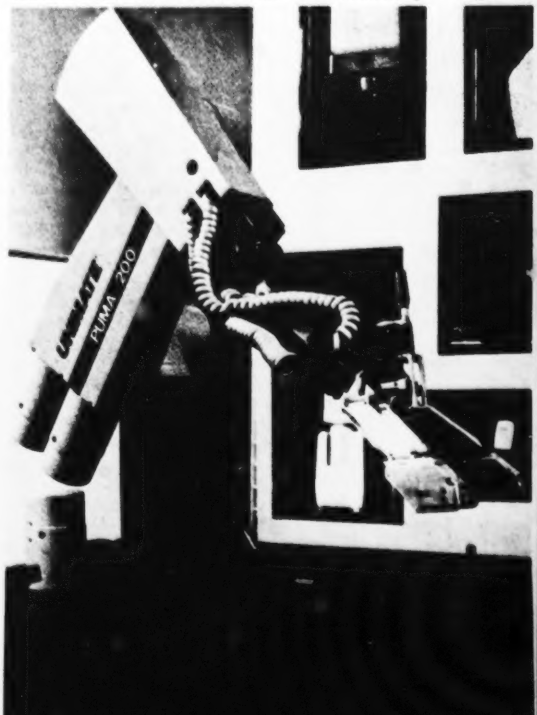

Figure 1. The Unimation Puma 260 robotic arm with activities of daily living workstation in background

responses were obtained on the post-test than the pre-test for the following characteristics of the system: sturdiness, safety, ease of use, obedience, value, and reliability. Negative responses included immobility, large size of workstation, and extended time to accomplish tasks. When asked: "Given what you know about a robotic aid, would you want one in your home?", mean responses pre-test were 1.8 on a 3 point scale (1=yes, 3=no) and 1.2 on the post-test. A video presentation demonstrating the activities with the disabled has been made. Future technological improvements and human-robot interaction considerations are being clarified.

Current barriers to the widespread use of robots in the health care setting include reliability, versatility, and cost. This study is helping to delineate in what areas technical advances are needed. For example, it was found that brushing hair proved to be very difficult without the use of an adaptive tool, and that the back of the head could not be reached.

Although robots have shown their worth in industry, surprisingly few studies on cost effectiveness have been conducted in a health care setting. By demonstrating that these tasks can be satisfactorily done, and in a reasonable amount of time, we hope to reduce attendant care costs by making quadriplegics more independent. The next step is to evaluate the robotic aid and workstation within the home setting. The decreased number of hours for which a client requires an attendant and any income generated from the client's vocation made possible by a robotic aid can be addressed in home evaluations.

ACKNOWLEDGEMENTS

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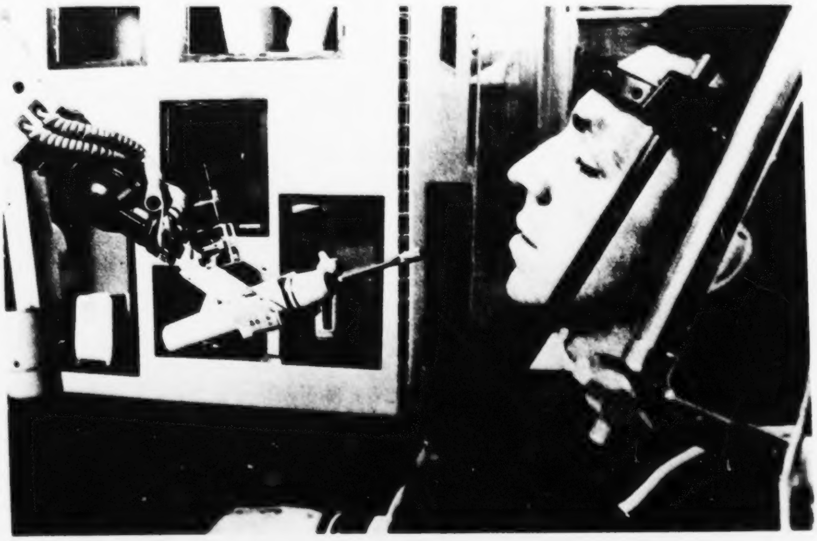

Figure 2. High level quadriplegic user commands robot through voice control to brush his teeth

ROBOTICS AT TUFTS-NEW ENGLAND MEDICAL CENTER
A Progress Report

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ABSTRACT

This robotics project was initially proposed as a demonstration of the application of human-scale robot manipulators as assistive devices for individuals with severe disabilities. The project targeted commercially available, low cost robot arms for placement and evaluation in long-term clinical and vocational environments. The basic premise is that the physical limitations of a person can be partially overcome with the addition of a mechanical arm that is under that person's control.

INTRODUCTION

When this project was begun in September of 1984, the intention was to demonstrate the effectiveness of augmenting the abilities of persons with multiple disabilities by introducing a robot manipulator into the environment. Robots are not dedicated devices; they are flexible, versatile and remove the need for a variety of dedicated appliances that further isolate the individual. They have the potential to operate in a number of areas, including personal care, medical therapy, personal clerical, vocational and recreational [5].

However, although technology is playing an increasing role in addressing the needs of a disabled population, we have not yet reached the point where clinicians, parents or employers who work or are somehow involved with a disabled person immediately see the need for and receive training in technological fields. Since robots are even newer to the arena than such developments as communication devices and mobility assistance, the familiarity of most people with robot applications is non-existent. In response to this reality, a flexible but efficient system had to be established: one which was versatile enough to meet the needs of the individual, yet simple enough to be usable by a clinician, parent, employer or even the disabled users themselves. In addition, it was deemed necessary that the system be affordable, since a high cost system, even if it meets the first two criteria, would be difficult to implement in practical applications on a broad scale in the near future.

With flexibility, simplicity and affordability as three of the primary guidelines, equipment was selected, clinical sites established and work began on primarily vocational task applications.

THE EQUIPMENT

Although some consideration was given to the Rhino XR-2 robot arm, the Scorbot ER-III from Eshed Robotec in Tel Aviv was the manipulator selected for use in the project. The Scorbot is a educational robot which uses servo motors to drive its five degrees of freedom and the gripper. The arm has a maximum vertical reach of 960 mm and a working radius of 610 mm in a 340 degree work envelope with a repeatability of +/- .5 mm. At maximum extension, the arm has a load capacity of 1kg. The motors are variable speed with maximums ranging from 14.7 deg/sec for the base to 105 deg/sec for the wrist pitch and the maximum gripper opening is 75 mm.

Scorbase, a menu driven programming environment which allows 100 pre-taught positions and 400 lines of code, is the manufacturer provided software. Scorbase has a set of 14 basic commands plus a comment option and is an unstructured language type [2]. The software is executed on an IBM Personal Computer (PC) or Turbo PC from P.C.'s Limited. Each PC is equipped with 640K RAM memory, a 20 megabyte fixed disk as well as a 360K floppy disk drive. The PC communicates with the controller through a standard RS232 port.

Each computer was also fitted with an SAR-10 Voice Plus Speech Recognition and Audio Response Board from NEC. This board allows recording of up to 250 words for speech recognition and 87 seconds recorded speech for audio response. Voice recognition can include audio feedback and the words can be clustered into isolate groups, decreasing confusion in near sounding words and enhancing recognition speed. Audio response speech can be broken into units and combined using macro strings. Using this system eliminated the need for separate speech recognition and voice synthesis equipment and lowered the over all cost of a station [9].

In addition to the above listed equipment, an RTX from Universal Machine Intelligence in England was also purchased. Although slightly higher in cost, this robot has several features which made it an attractive possibility. The arm is a servo driven robot with a SCARA configuration that has six degrees of freedom plus the gripper. The working envelope is larger than that of the Scorbot, although the extreme measurements are approximately the same (910 mm vertical, 684 horizontal). This is due to the straight-line vertical capability of the arm. The load capacity of the arm varies with extension and orientation but ranges from 2kg to 4kg. The motor speeds range from 41.1 deg/sec for the shoulder to 123.2 deg/sec for the wrist yaw and can be more finely controlled on the RTX than on the Scorbot [11]. The RTX is being considered for applications which exceed the capabilities of the Scorbot.

THE CLINICAL SITES

Two clinical sites were selected, both supporting vocational and pre-vocational training programs. The Campus School is located on the Boston College Campus and is private, non-profit and non-residential. It serves a primarily non-vocal population with multiple disabilities. The students range in age from 5 to 23 years. The school emphasizes pre-vocational and vocational training in addition to the normal academic curriculum, and conducts a sheltered workshop which includes assembly, piece management and commercial (including sales) experience. The majority of students capable of using a computer based communication system are using a single switch interface.

The Massachusetts Hospital School is a publicly owned residential facility located in Canton, Massachusetts. The school provides comprehensive educational and vocational services to 120 severely disabled individuals. The school has an active rehabilitation engineering program which emphasizes nonvocal communication, powered mobility and microcomputer applications. As a result of a survey of recent graduates, the school is placing a high priority on preparing students for employment after graduation.

DEMONSTRATION TO DEVELOPMENT

From the outset, it became clear that the software supplied by the manufacturer was not equal to the task. Robot operations, especially those in a human services

Center. Since the lab has a strong emphasis on communication and computer access, many of the interface issues were already being raised in parallel projects. In addition, the concept of a robot development environment that supported a broad selection of robot arms and allowed clinical development gave rise to the possibility, now being investigated, of a similar strategy being applied to the communication field, prompting discussion on the possible development of a brother language to Calvin, affectionately named Melvin.

APPLICATIONS

When Calvin reached the point in its development where it could support clinical applications, additional stations were established at the clinical sites and the applications programming focused on three major projects, with a number of smaller investigations being conducted in the laboratory setting.

A General Applications Package

It became evident that some tasks were basic enough to be generalized and made part of a clinical software package. Tasks such as sorting, some basic styles of packaging or assembling kits are standard elements in a vocational or pre-vocational setting. The first major project, therefore, was actually a collection of applications assembled into one menu-driven program called Helpmate. Helpmate combines a variety of common workshop tasks as well as some recreational activities and some user assessment programs into a highly user friendly package. Because the environment of the robot was reasonably structured, yet retained a number of unstructured elements and unpredictable events, the programs needed to combine automation with user decision making freedom at critical points and, occasionally, complete user control of the robot. They also needed to deal with error detection and correction and be open to variable input and output options.

At present, the package includes five individual tasks or routines. The first is a basic sorting task which allows the user to sort a variable number of different type objects into individual bins. The speed of the robot arm, the method used to control the arm (voice, variable number of input switches, keyboard, etc), the location of the various bins, the method by which a target bin is selected, and several other parameters are all variable, thus making the program general enough to be used in a wide range of situations. The second application is a kit assembly program, which is essentially the reverse of sorting. Items from various bins can be assembled into a common location to create a kit. Many of the configurable dimensions of the sorting program are also configurable for the kitting program. The third element of the package is not actually a specific task, but is rather a practice program which gives the user direct control over the robot using whatever input mode they are comfortable with. Since this module is included in most of the other programs, it is isolated as a separate unit here for teaching purposes. The fourth element in the package is a switch assessment program which produces a report on the user's accuracy and speed in pressing one of eight designated input switches. Primarily designed for the Campus School population which uses input switch interface, the program rewards accurate switch closures with a small robot dance and records response time. The re-enforcer is easily changeable (i.e: The robot could present the user with a cold drink for successes instead of dancing). In time, this program is intended to be extended to assess actual robot control and to use other input peripherals. Finally, the package includes one recreational program. The robot plays checkers using any of the input modes available to the package in general.

application, are subject to a great number of uncertainties and typically unstructured,therefore variable, environments. A great deal of robot programming addresses the need for error detection and correction, which Scorbase cannot handle effectively. In addition, Scorbase is primarily limited to position control, which presupposes a relatively fixed environment not common to rehabilitation applications. Finally, a low cost robot manipulator is not typically replete with sensor capabilities, and the Scorbot is not an exception to this tendency. For this kind of application sensor based decision making, which usually falls into the four areas of motion initialization and termination, selection of alternative motion strategies, obtaining piece or environment features and complying to external restraints, must be replaced by human interaction with the robot [7]. Scorbase does not have capabilities for interface extension.

Using Scorbase, the only viable tasks were dedicated tasks involving little or no user intervention. Scorbase, designed to be a teaching environment for robotics, violated one of the first rules of rehabilitative robotics: it did not address the needs of the target population [6]. What was needed was a more flexible robot environment, specifically designed with the rehabilitation population in mind. With this realization, necessity prompted invention, and the Rehabilitation Engineering Center developed its own robotics environment called Calvin.

Since Calvin is discussed in detail eslewhere [8][3], a brief description will suffice here. Calvin was intended to be useful and usable by a wide range of practitioners, from the parent to the programmer. It was intended to be easily extended to include additional peripherals, since there is a good chance that the keyboard is not accessible to a severely disabled person and a monitor may not be the best way to feedback information from the system. It was intended to be compatible with a number of candidate robots, to extend its field of practical applicability. It was intended to be interactive and capable of interactive tasks: essentially an interpreter. Finally, the code or language structure was intended to be readable and maintainable. These goals were all achieved during the course of the project and Calvin became the backbone of the demonstrations.

Calvin itself is a user friendly development environment that is essentially an interpreter. It has readable code patterned after C and including attributes of Logo, all of which makes for easily maintained programming. It has four basic classes of functions: basic program flow controls, mathematical and trigonometric functions, input/output or peripheral control including good screen management capabilities, and the drivers for the specific robot in question. Calvin is capable of error detection and variable response as determined by the user. Finally, Calvin's ability to define functions of increasing complexity (similar to C) makes the language highly vertical, ranging from point to point control up to task specific control [10].

To augment Calvin, the actual C library of drivers used by Calvin is retained as a separate entity which can be used for more sophisticated programming applications in C. This gives a professional programmer access to the capabilities and powers of C not included in Calvin, which is intended to remain simple enough for use by a clinician or parent. This library tends to be used for complex, large scale applications, such as the three reviewed below, while Calvin is used on-site for small scale teaching applications, or user specific needs (i.e: getting a glass of water, etc.)

The development of Calvin and interface development overlapped with other foci of the Rehabilitation Engineering

Other tasks are slated to be developed for the package, and there is some thought being given to the possibility of disambiguating Helpmate into a variety of thematic packages, such as a Playmate which would contain a variety of robot recreational activities, or Workmate for sheltered workshop applications. At present, The Helpmate software package is the primary package being used at the Campus School, where a strong focus is being placed on training and user interface.

A Telephone Switchboard Project

The second major applications task utilizes the robot arm with the Voice Plus speech recognition system to run an AT&T switchboard. The highly structured environment and easily defined repeatability of the task combine to make it an ideal robotics application. Further, the existence of several thousand of these switchboards and the promise this task shows for making a previously unemployable person employable makes this application that much more attractive. The Massachusetts Hospital School uses one of these switchboards and the Administration of the school has indicated their willingness to train several of their high school aged students to work as telephone operators. The students selected are disabled due to muscular dystrophy or spinal cord injury and have appropriate vocal skills, but lack the manual skills to operate the switchboard. The task breaks down into identifiable parts such as call transfering, connecting extensions, paging and dialing both in and out of house numbers.

The software itself consists of the main execution program being written in C at the R.E.C. using the robot library; three data files containing the vocal command table, the digitalized voice for speech recognition and the position arrays for the robot; and a teach module to train the robot for the various positions it will need to know. The program itself is in the later design stages, needing only to have a well designed visual display. The teach program is in the design stages at this point, but since the program is capable of reading a position file generated by Calvin, Calvin can be used to create the positions until this component is complete.

Industrial Quality Control

The third and final major project involves quality control work at Instron of Canton, Mass. Instron has already hired five students from M.H.S. and has indicated interest in hiring an additional student and cooperating in the establishment of a robot established work environment. Three separate tasks are being evaluated as possible projects and the programming and lab mock-up are slated to begin in April of 1987. The first two tasks are similar and involve product testing on a pass/fail level. The first involves testing of cables and the second would test the capacity of resistors. The third task is a product identification task which would require some simple interface with the company mainframe to get listing of purchase orders, and would entail selecting and displaying a part so that the item number of the part can be compared with the item number on the purchase order to assure that the correct part has been delivered and/or packaged. Again, the reasonably structured environment together with the need for user decision making makes these three tasks ideal.

CONCLUSION

Development continues on Calvin, the various robot libraries and assorted applications tasks. At the two clinical sites, work with the students is occuring at two levels. First, the students are being trained and interfaces between them and the manipulator continue to be developed. Second, severely disable individuals are being prepared, with the cooperation of employers, clinicians and parents, for transition from pre-vocational to full time employment situations. In addition to these hoped for and expected developments, the robot stations are producing social and behavioral shifts which will merit study and development. Students using the arm over a period of time begin to develop skills such as depth perception, decision making and spatial orientation not otherwise drawn on. The robot station may have as much to contribute to the classroom and physical therapists office as it does to the work place and daily living environment.

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DEVELOPMENT OF THE MANUS WHEELCHAIR-BORNE MANIPULATOR: A PROGRESS REPORT

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ABSTRACT

An outline is given of the developments in the Dutch MANUS Project, highlighting elements of the mechanical, electrical and software designs. A first working model has been realized to test design concepts and support further system developments.

INTRODUCTION

The objective of the MANUS Project is the development of a wheelchair-mountable manipulator system with a modular micro-computer assisted control system, adaptable to persons with severe disabilities of all four limbs. The design objetives and the control philosophy have been discussed in the 1986 WRF-RESNA workshop on robotic aids (1). The functional elements are represented in fig. 1. The system consists of:

1. The mechanical arm mounted on the wheelchair.
2. Control transducers adapted to the particular user.
3. The firmware system for motor servo control, coordinate transformations, and control procedures to adapt the system to the human operator.

Control procedures will be configurable at different levels through an external computer. At the lowest level this will consist of a selection of the appropriate procedures from a library, which could be done by e.g. an occupational therapist. One of the procedures will serve to control wheechair movements, using the same control transducers. A display mounted near the gripper (fig. 4) and a sound signal will provide an elementary feedback to the user. A link to external computers may be realized in the future. We are aiming for an integral optimization of the electro-mechanical and software design, weighting factors as functionality, safety, social acceptability, reproduction costs and maintainability.

THE MECHANICAL SYSTEM

A first model of the mechanical system has been realized (figs. 2 and 3) and is used to test and improve the various concepts of the design. Some of the highlights of the design are:

- A mechanical configuration consisting of an articulated arm on a telescoping base, with 8 degrees of freedom including gripping.
- The arm has a range of 720 mm at the wrist joint, or about 850 mm at the gripper.
- A rotating and telescoping cylindical base provides a vertical displacement of 250 mm of the shoulder joint, allowing objects to be fetched from the ground.
- The offset shoulder construction positions the upper arm further away from the user, providing more "living space". Together with the different lengths of the arm segments and the telescopic movement it allows the arm to be foulded away next to the column and stocked below an arm rest next to the wheelchair when not in use.
- Two of the three degrees of freedom at the wrist joint allow continuous rotations of the gripper (1 and in fig. 3).
- All motors and gear boxes are placed within the column to keep inertia down. The movements are transmitted to the peripheral joints through belt drives, gears and concentric hollow shafts, all contained within the arm enclosures.
- Mechanical uncoupling of elbow and shoulder movements and compensation of gravity forces allows for the use of small DC motor drives.
- A modular construction of the arm segments facilitates maintenance of the system.
- Slip couplings on shoulder and elbow joint drives protect both the user and the system against excessive forces.
- Aluminum castings and standard steel tubings have been used to reduce costs. Some of them may be replaced by composite materials in the next design stage.
- The manipulator will be easily detachable from the wheelchair. Special kits will be developed to facilitate installation on different types of wheelchairs.

ELECTRONICS AND COMPUTER HARDWARE

The electronic system will consist of three main parts (fig. 4):

- A print in the rotating column containing FET motor drives, opto-electronic sensors for angular position sensing of the motors, and communication circuits.
- A control box permanently attached to the wheelchair and containing an 80186 computer, memories, transducer interfaces, power supply, and communication interfaces. A separate interchangeable print contains the interface for the specific wheelchair used.
- An external computer (IBM-PC), connected only to reconfigure the system but not required for its autonomous operation. It might also be connected when docked at a structured working station for extended high-level programming.

A special serial bus is under development to simplify wiring, both between the box and the arm and between moving elements within the arm.

SOFTWARE DESIGN

The object code resident in the wheelchair-borne system has to operate under real-time conditions at intervals of 20 ms. It is created in four modules on an IBM-PC environment (fig. 5):

1. The body of the real-time system, including servo controls, fast coordinate transformers, communication interfaces, and "patchboard

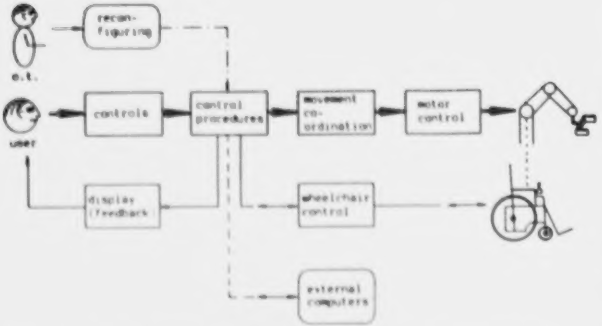


Fig. 1 Block diagram of the MANUS wheelchair-mounted manipulator system

functions" is compiled from a PLM source program and installed on PROMS.

2. A user control mode (1) may be defined in a "patchboard", chaining together elementary functions available in the object program. Thus, a library of patchboards may be realized, using a "patchboard editor", and downloaded to EEPROMS.
3. A number of patchboards may be made accessible to a particular user by some mode selection procedure, together forming a user "configuration". A library of different configurations will be realized, optimized for different types of users.
4. On the therapist level, access is given to the selection of a configuration from the library and modifying its parameters (within a certain range) to adapt the system to a particular user.

STATUS AND FURTHER DEVELOPMENTS

The developments are carried out from the mechanical system back towards the human operator (fig. 1). At the time of this writing (March 1987) a working mechanical model has been realized, following numerous plastic "sight models". Motor servo's have been installed and are operating. The basic Cartesian coordinate transformer has been implemented and tested. Simple movements may be carried out under preprogrammed or potentiometer control, but the more elaborate man-machine configurations have yet to be implemented. The purpose of the present system is to test and develop the concepts adopted and to serve as a tool for the software developments. Numerous improvements have already been made on this model and tests have indicated where further improvement are needed. The basic concept of the system proved to be satisfactory and will be retained.
In the next phase further improvements will be made on the mechanical design, in particular to reduce friction in the transmissions and improve wrist and gripper mechanisms. Some of the gearing ratio's have to be changed to speed up wrist movements, and drive mechanisms will be tested on reliability and life expectancy. The use of light-weight composite materials will be considered and the design will be reviewed in general to reduce production costs.

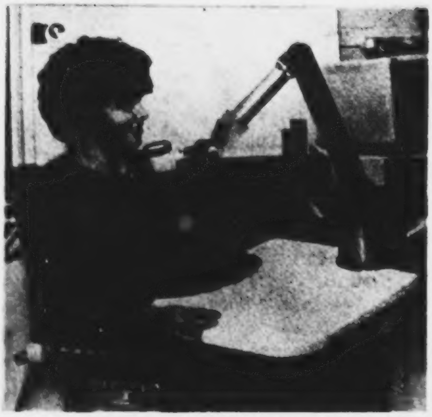
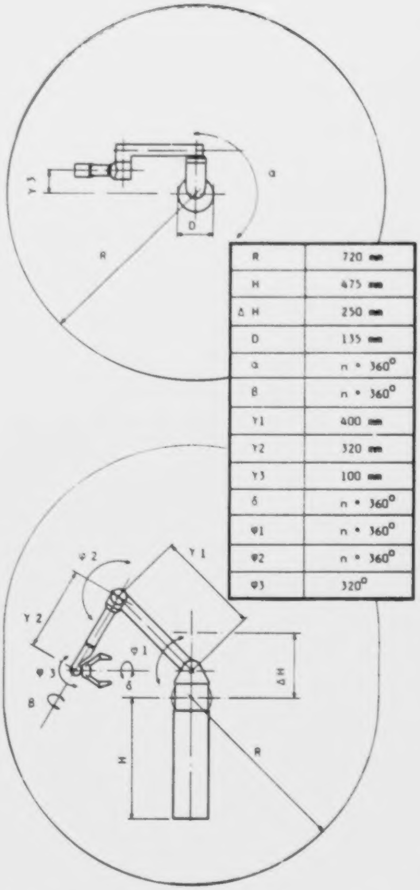


Fig. 2 Mock-up of the first model next to a wheelchair



R	720 mm
H	475 mm
Δ H	250 mm
D	135 mm
α	$n \cdot 360^{\circ}$
β	$n \cdot 360^{\circ}$
$\gamma 1$	400 mm
$\gamma 2$	320 mm
$\gamma 3$	100 mm
δ	$n \cdot 360^{\circ}$
$\varphi 1$	$n \cdot 360^{\circ}$
$\varphi 2$	$n \cdot 360^{\circ}$
$\varphi 3$	320°

Fig. 3 Geometry and range of movement of the mechanical arm

The firmware design will be further developed and tested, strategies will be implemented to shape accelerations, deal with singularities and system limits of velocity, angles, forces, motor currents and temperature. Coordinate transformers for a "piloting" mode (1) and for cylindrical coordinates will be added, as well as start-up, safety and programming procedures. Simultaneously, the patchboard elements and the configuration-building software will be implemented.
Three prototypes should be working by the end of 1987, two of which will also be used to study spin-offs in robotics.

ACKNOWLEDGEMENTS

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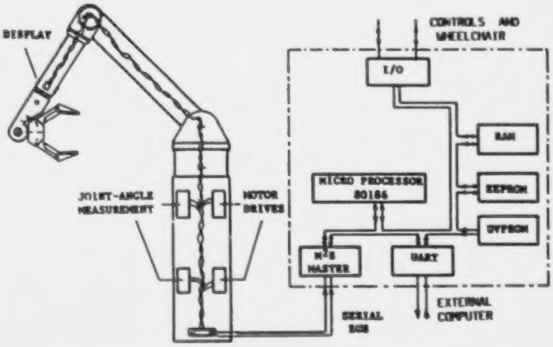
DISPLAY
CONTROLS AND WHEELCHAIR
I/O
RAM
MICRO PROCESSOR 80186
EEPROM
JOINT-ANGLE MEASUREMENT
MOTOR DRIVES
UVPROM
M²S MASTER
UART
SERIAL BUS
EXTERNAL COMPUTER

Fig. 4 The wheelchair-borne hardware system

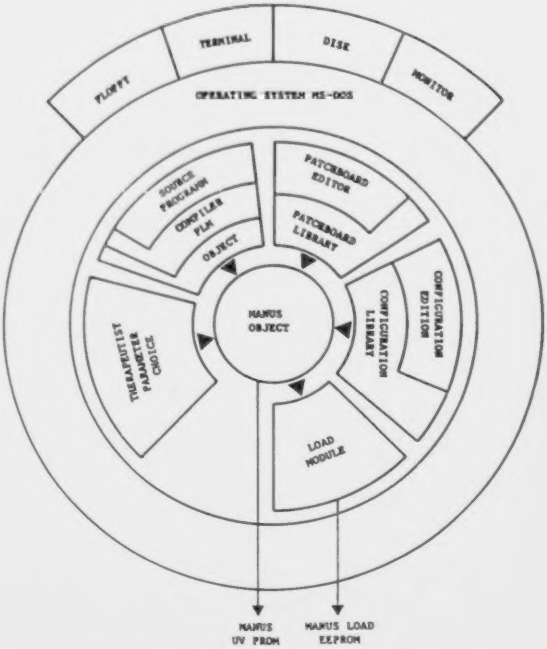
TERMINAL
DISK
FLOPPY
MONITOR
OPERATING SYSTEM MS-DOS
SOURCE PROGRAMM
COMPILER PLM
OBJECT
PATCHBOARD EDITOR
PATCHBOARD LIBRARY
CONFIGURATION EDITION
CONFIGURATION LIBRARY
MANUS OBJECT
THERAPEUTIST PARAMETER CHOICE
LOAD MODULE
MANUS UV PROM
MANUS LOAD EEPROM

Fig. 5 Creation of software modules on the IBM-PC and downloading to the system memory

DEVELOPMENT OF A ROBOTIC FEEDING DEVICE FOR DISABLED INDIVIDUALS

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Introduction

The act of eating is often taken for granted, but many disabled individuals cannot accomplish this task. Moreover, the motions and control required for this "simple task" are, in fact, quite complicated. Extensive work has been done in industrial manipulator control, and some work has been done in manipulator control for quadriplegics to provide general motions under the operator's control (Seamone and Schmeisser 1975; Guittet, 1976; Haggerty, 1977; Ramey, et al, 1979).

This research concerns the development of a practical robotic feeding device (Fig. 1) that is both technically and financially accessible to the entire disabled population. This main objective translates into several minor objectives: the device should be adaptable to handle differences in individual operators, should be relatively inexpensive, and should be portable.

Disabled individuals probably have more diverse capabilities than able-bodied persons. Therefore, the prototype system was modularly designed for easier adaptability. The input module, or the interface to the operator, is the only hardware that will be changed for different operators. Naturally, some software changes may be required to "tailor" the system to an individual.

Design

In reviewing the design of the current manipulator feeder systems, considerable improvements can be made in two areas: scooping effectiveness and user-flexibility. Therefore, it was the goal of this project to make improvements in these areas.

Feeding can be modeled as moving the spoon through some type of rotation and translation on the plate (scooping), followed by lifting the spoon up to the operator's mouth, keeping the spoon horizontal to prevent spillage. The operator's mouth, or the endpoint, can not be guaranteed for every scooping cycle. The spoon must then be returned to the plate for the next sequence. Previous designs were either very mechanically complicated or not complicated enough. Unnecessary complexity arose from using general manipulators, which had too many degrees-of-freedom, and therefore required more sophisticated controllers. Simple designs resulted in decreased scooping effectiveness and little flexibility. Therefore, the objective of this project was to optimize the feeder design by finding the middle ground in these tradeoffs.

In the prototype feeder, certain aspects of the feeding cycle were built into hardware, decreasing the computational needs while the flexibility of the system was ensured by keeping the major variables in software. For example, the orientation of the spoon is held horizontal by the linkage, instead of being computer controlled, at all times except scooping. The special tray is probably the biggest advantage of the new feeder as it keeps the different food types separated and greatly simplifies the scooping motion. The previous examples of computer controlled feeders used generalized manipulators not designed specifically for feeding.

The prototype feeder consists of two major components: the computer and the manipulator. The small 128K computer is manufactured by Intel Corporation, and is designed for small control applications. Computer software was developed on a HP1000 system that simulated motion of the arm during scooping. This Fortran program provided the "backward" kinematic solution of this mechanism by plotting the link angular positions given cartesian coordinates of the wrist point. The spoon angle was kept at a constant (horizontal). Ten points were chosen, nine along the tray and one at the mouth. This was done for different link lengths and different relative positions of the tray in the workspace.

The manipulator system basically consists of a three-link planar "arm" and a linearly tracking tray. Stepper motors are used to position the arm in the desired orientation. Stepper motors are chosen over DC-Servo motors because stepper motors are easier to interface with computers. Stepper motors require digital signals and these are readily available from a computer without having to use analog-to-digital converters (ADC) or digital-to-analog converters (DAC). Along with this interfacing advantage, stepper motors can be operated in an open-loop fashion.

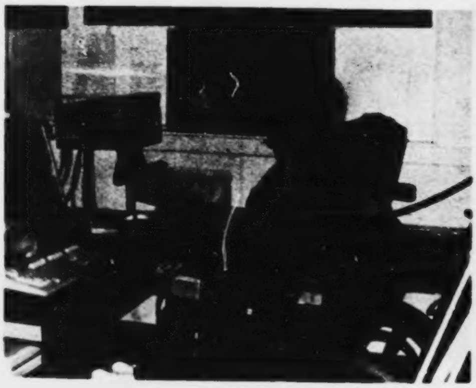

Fig. 1 Disabled Individual Using the Robotic Feeding Device.

The arm is made of 1/8-inch walled extruded aluminum square tubing. The tubing is modified to minimize the weight and also for component clearances and accessibilities. The arm is supported above the tray and has at its end a spoon which carries the food from the tray to the operator's mouth.

The sanitary plexiglass tray has four 1-inch wide and 4-inches deep compartments to hold different food types. This clear material is used to allow the operator's view of the food, especially in the determination of the quantity and food type in any compartment. These compartments are shaped so as to facilitate the scooping action; in other words, to help the food onto the spoon. The rounded corners in the front and back prevented food from being inaccessible. The angle in the front pushed the food onto the spoon, and the back angle allowed the spoon a convenient entry angle.

The tray mechanism included several components: a linear bearing to which the tray bracket and subsequently the tray is affixed, a stepper motor to drive the tray back and forth via a rack-and-pinion drivetrain, and an optical switch. The plexiglass tray fits into the tray track which was driven back and forth by a stepper motor. The whole assembly is mounted on a 1/4-inch thick plate which is in turn mounted to the base. The plate could then be mounted in any X position on the base, leaving room for adjustments. This special tray is perhaps the major hardward difference between this project and the previous works, none of which used modified plates.

The spoon is observed to have a flat front edge to facilitate frontal scooping rather than traditional side scooping. A plastic spoon is chosen to be soft and thereby lessen the chance of injury. Further, a bright color is used to be more visible and easier for the operator to track.

Feeder Operations and Controls

The control system consists of three major components: human operator, microcomputer, and stepper motors. The disabled operator controls the manipulator by providing the input commands to the computer which, in turn, interprets these commands and sends the appropriate signals to the stepper motors which move the manipulator. The feeder is considered open loop because there is no electronic feedback, position or otherwise, of the manipulator to the computer. However, during operation, the operator provides a "feedback" by watching the arm move and guiding it accordingly via the joystick. Note that the tray is always run open loop using the technique of counting steps as they are sent.

The control system is designed to fully utilize the operator's capabilities without requiring "too" much input. This is line with the design philosophy of keeping eating a simple task. This further highlights the need to build a system which can be tailored to each operator. The operator communicates to the computer via an individualized input module. For this prototype feeder system, a standard electric wheelchair control box was used as one of the input modules because of the operator's familiarity and its availability. This control box was similar to the one used daily by the operator. The second input module consists of four pushbuttons that, when activated, causes certain procedures (SCOOP, RETURN, TRAY) to be performed. The two degrees-of-freedom (2-DOF) joystick controls the velocity of the arm. Velocity control was chosen for this application because it has been shown to be most effective way for a human to control a manipulator via a joystick. The pushbuttons were arranged in an ergonomic semicircle so the operator could rest his palm on the joystick and his fingertips on the pushbuttons (Fig. 1). Initial tests using able-bodied operators showed that "scooping" could not be controlled using a 2-DOF joystick as was originally planned. The scooping motion was handled by the computer with the operator simply signaling the computer to begin the scooping motion.

Paramount to the design, along with the user-flexibility, was maximum operator control over the food presentation. This included choice over which food type and the speed of food presentation to the mouth. "Food type" control is accomplished by using the compartmentalized tray which is controlled by the two pushbuttons designated "tray right" and "tray left."

The microcomputer chosen for this application was a system based on industrial quality Intel single board computers. This machine was readily available and has more than ample capabilites for the application. It is anticipated that a final production model would use a single chip micro-controller as the control device.

There are four distinct functions of the feeder that are directly controlled by the operator: scooping, returning the arm to home, moving the tray right and left, and moving the arm via the joystick. Basically, these could be accessed in any order, except for certain built in safety precautions. For example, attempting to move the tray while the spoon is inside the tray would cause a warning light and no movement of the feeder. Also, the feeder would not let the operator scoop if the arm is not in the correct position. Finally, both the arm and the tray have preset range-of-motion limits that if exceeded would cause a warning light. Three LED's are used to indicate when the feeder power is on ("power") and to warn the operator that he has attempted to exceed the limitations of the feeder ("tray fault," "arm fault").

For this prototype robotic feeder system, a typical sequence of operation would proceed as follows:

1) System set-up with operator in position and feeder fully stocked with a meal and power is on.

2) Feeder is now in the home position, that is, the arm is ready to scoop from the first tray compartment.

3) Operator decides if he/she wants the food in Compartment #1. If not, the tray can be moved via the "Tray left" and "Tray right" switches.

4) When the desired compartment is lined up, the scooping action is initiated by pressing the "scoop" button.

5) After the scoop is finished, the spoon is guided to the mouth via the joystick.

6) Once the food is taken from the spoon by the operator, the arm can be returned to the scooping position by simply pressing the "Return' button.

7) Repeat steps 3-7 as desired.

Step 4 should be expanded by stating that the operator needs to position the spoon down into the compartment an appropriate depth, depending on how much food is in the compartment.

This sequence offers a great deal of control by the operator (speed of sequence, food types, scoop size, etc.) without overextending his/her capabilities.

Discussion/Evaluation

As it was stated previously, for this robotic feeder device, the operator provides the feedback for the control system with the amount depending on the capabilities of each individual operator. A 21 year-old male student, afflicted by multiple sclerosis (MS), who could operate a joystick and pushbuttons was chosen to evaluate the prototype feeder. He was able to operate a joystick and thus provide velocity feedback to the system for controlling the arm motion. The MS patient was chosen because his configuration would require more signal processing and ergonomic design than other disabilities. The subject for this evaluation can by no means be considered an average representation of the disabled population. In fact, for the characteristic motor skills that were important for this project, a person with average skills probably could not be defined. Therefore, future feeders will need several different control algorithms to match the wide variety of operators. Fortunately, this can be accomplished easily in software.

The evaluation of the prototype feeder consisted of extensive use of the feeder by both able-bodied and disabled operators. During the last three months of the project, over 100 hours of operation were logged. Three distinctly different food types were used during this evaluation: hard and dry (peanuts), chuncky and sticky (pickle relish), and smooth and sticky (yogurt and pudding). All of the food types were "scooped" and delivered to the operator successfully. The final and most conclusive tests involved, of course, the disabled operator. He used the feeder a total of four times during development, and during the final session he was able to feed himself for the first time in a long time. The first three sessions were needed to perfect the system and to allow the operator to become familiar with the equipment.

Initially, two students were available for participation. The other being a quadriplegic due to a spinal-cord injury who could operate a "puff-and-suck" controller. The "puff-and-suck" controller is a common input device usually used to control a wheelchair by a severely disabled quadriplegic having absolutely no control over his/her extremities. A feeder configuration for this person is under consideration for the future development/improvement of the system.

Paramount to the usefulness of this device is the ability to be used by several different operators with varying abilities. The prototype has proven that it can be used by one particular operator. Other operators need to have the feeder configured to them. This will involve tailoring the input modules to their abilities and developing more software.

To make this project more than an academic exercise, it was an objective to develop a device for production. To fulfill this, the authors have envisioned a second-generation feeder to be designed after some improvements and other configuration adaptations have been made. The next feeder should probably be constructed mainly of molded plastic. For example, the entire prototype structure of base, vertical supports, and motor base could be replaced by one molded piece of plastic. The arm and tray could also be made of plastic. This would have the advantages of being lighter, more sanitary, and more aesthetically pleasing than the prototype. Most importantly, these pieces could be more quickly and more cheaply produced, especially in mass quantities.

The goal of this rehabilitation engineering project was to utilize state-of-the-art science and technology for the direct benefit of physically disabled individuals. While this robotic feeder system was specifically configured to accommodate this individuals disabilities, it could be very easily modified to serve as an appropriate feeding device for other physically handicapped individuals. It is hoped that this device and others that will follow will endeavor to make this individual's life and those of others more enjoyable, productive, and free.

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Object Localization Using Multi-resolution Sensing

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ABSTRACT

In the rehabilitative robotic applications, the robot's ability to locate rapidly, and accurately an object in the workspace when the human user specifies the initial, rough position of the object, is highly desirable. This paper describes a method where multiple sensors of varying resolutions are used to determine the exact position and orientation of an object, from the internal model of the object, and its given approximate location. It will show that by guiding the sensation with the information obtained from the preceding, lower resolution sensors, one can reduce the computational load and the time required for the localization process. Upon completion of the localization procedure, the robot should have sufficient knowledge of the object to grasp and manipulate it.

INTRODUCTION

Robotics in rehabilitation has been a focus of great interest in the past several years, not only for its potentials, but also for the special challenges it presented for the researchers. The presence of a human being in close proximity and close interaction with the robot distinguishes the rehabilitative robotics from other applications. The method presented in this paper seeks to emphasize this distinction in developing a sensory system that will equip the robot with adaptive capabilities that are crucial for realizing the true potentials of the robotic application in rehabilitation.

Need for adaptive capabilities

A robotic aid for the handicapped patients [1, 2] must operate in highly variable and unpredictable conditions. Unlike other robotic applications--e.g. industrial robots--the environment is much more difficult, if not impossible, to control. Consequently, a special demand is put upon the robot's adaptive capabilities, and not as much upon the accuracy, repeatability, and speed. The ability to recognize and locate various objects in the workspace is fundamental to such adaptive capabilities. In order to attain this, we are currently developing a multiple sensor system that will utilize the multi-resolution pyramidal data structure [3] to locate and identify various objects.

Why not vision

The object recognition and localization problem has been a goal of computer vision for many years. Researchers in this field have developed numerous sophisticated techniques that accomplish this to varying degrees of success. However, any vision system inevitably must deal with the problem of extracting 3-dimensional geometric information from a 2-dimensional array of grey levels. Although many tools are now available to do this [4], they all incur a cost, both in the hardware and in the computation time; furthermore, this cost increases as one reduces the constraints on the system's operating environment. In a nearly unconstrained environment that rehabilitative applications require, this cost becomes prohibitive. Therefore, multi-resolution sensing acquires the 3-dimensional information directly from ranging and tactile sensors, and depends on the human user to provide the initial constraints for the sensory search.

Human participation

In the rehabilitative application, a human is always available, and therefore can participate in various task executions. While object recognition is a highly complex and time-consuming operation for the computer, humans can perform this task with remarkable ease and speed. Furthermore, humans are very good at determining the relative positions and orientations of objects. In so far as they are available, such valuable resources should not be left unused. On the other hand, the system should not burden the user with the tedious and repetitious chore of directing the robot incrementally from the beginning to the end of the task execution. The robot should be autonomous to the extent that it can complete a task on its own once the human provides an initial set of constraints--i.e. description of the situation.

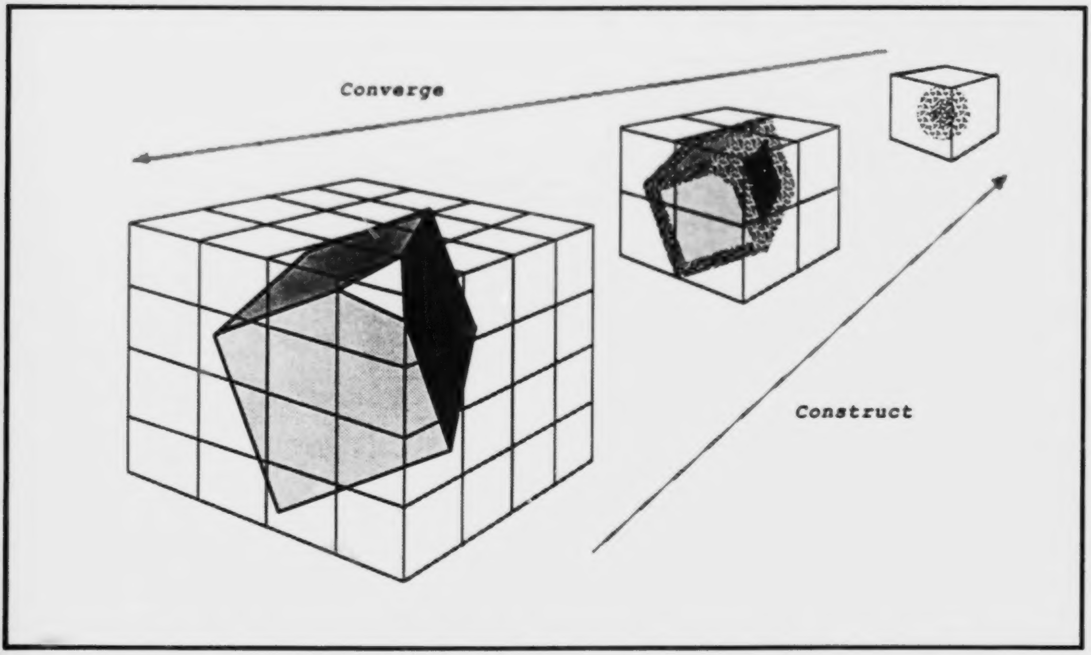


Figure 1. Multi-resolution pyramid allows one to represent the world from different levels of resolution.

Multi-resolution sensing

Multi-resolution sensing incorporates the user and the robot into integral components of a symbiotic system. The human performs the object recognition, scene-analysis, and the most global decision making operations; while the robot performs the subsequent localization, verification, and manipulation tasks. This setup is efficient and cost-effective; furthermore, it should give to the user a sense of control rather than dependence towards the robotic aid.

PROBLEM

To demonstrate the multi-resolution sensing, we focus on the object localization problem. We assume that the human provides the identity of an object and a crude approximation of its location. The robot's task then is to find the exact position and orientation of the object, verify that it *is* the object, and determine a set of feasible grasp sites and configurations. While this is the simplest form of the adaptive capabilities, it is a fundamental kernel for all other adaptive capabilities. For now, we assume that there are no other objects in the vicinity to confuse the system; we thereby isolate localization from disambiguation [5].

CONCEPT

Although we circumvented the complications pertaining to the degenerate transformations of 2-dimensional image processing by using only the ranging and tactile sensors, we now confront the problem of interpreting extremely sparse set of data. During one sampling period, an ideal ranging device only "sees" along a single line segment in space; a tactile sensor "feels" only a single point of contact. If the robot is to operate in real-time, in cooperation with an impatient human, the system has no time to grope randomly for the object. What few sensory data the system takes must be meaningful. Multi-resolution sensing ensures that these data *are* meaningful by providing a **context envelope** to each stage of sensing.

Multi-resolution pyramid

Multi-resolution technique decomposes the world into multiple layers of varying resolutions. Multi-resolution pyramid is a data structure whose levels are successively condensed representations of the previous, lower resolution layers. (In image processing, for instance, this corresponds to the repeated averaging of image intensities with each layer of resolution [3].) As one increases the resolution of the observation, the amount of sensory data also increases, and hence the term *pyramid* (see figure 1): in effect, one is trading the uncertainty in data accuracy (detail), for the uncertainty in ambiguity (location of sensing relative to object). And though the overall uncertainty remains constant, one can choose to examine the world from a different perspective by changing the resolution.

Multi-resolution processes

This allows one to isolate successively smaller volumes of interest as one employs the sensors from the low to high resolution order in a process we call ***converge***. Because no time is wasted exploring irrelevant regions, this sensing scheme is extremely efficient. Starting from the very low-resolution sensing, each sensory stage isolates a smaller region within its sensory scope for the next, higher-resolution sensing. In effect, every stage of sensing is given an **envelope** (the region of interest) and the **context** for exploring that envelope. Consequently, a set of very sparse data becomes meaningful in the localization process.

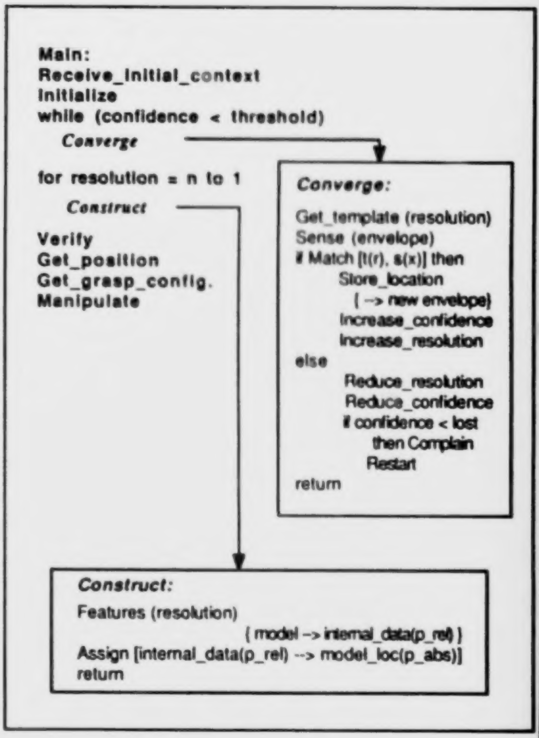
Upon the completion of the highest resolution sensing, a process called ***construct***, traverses the pyramid back from the high to low resolution levels. The process takes the quantitative sensory data and at each level transforms them into an increasingly more qualitative set of features, until ultimately a complete **interpretation** is formed. This effectively allows one to instantiate the world in different resolutions, and thereby facilitate the development of much more complex adaptive capabilities to follow the localization.

Internal model

Above processes require an internal model of the object: the *converge* process needs it to define the contexts and the templates, and the *construct* process needs it to form and verify the features and the interpretation. Although multi-resolution sensing is not confined to any one representation of the object, the internal model should easily transform to match the form of sensory data at each level of resolution.

IMPLEMENTATION

The multi-resolution sensing system consists of 3 main components: multi-resolution pyramid data structure, internal model of the world, and the multiple sensors. The human user initiates the localization procedure by providing the identity of the object to be located, and his approximation of its location. The robot then begins its lowest resolution sensing by first deriving from the internal model the template t(r) which corresponds to this resolution. Then the system explores the user-specified region (context envelope). When the template-matching operation detects an expected set of sensory data, the system records the origin of this data and goes on to the next higher resolution-level of sensing. This matching process continues toward the base of the multi-resolution pyramid. The *converge* process terminates when the base (highest resolution sensing mode) is reached, and the *construct* process begins. At each resolution level, the located data origins and their context are combined to confirm the matching "feature" on the internal model. When this process reaches the tip of the pyramid (lowest resolution data), an interpretation for the sensed object is completed, and the system should now have at its disposal the exact position and orientation of the object, and its various grasp site(s) and configuration(s). Figure 2 illustrates this algorithm.



```
Main:
Receive_initial_context
Initialize
while (confidence < threshold)
   Converge

for resolution = n to 1
   Construct

Verify
Get_position
Get_grasp_config.
Manipulate
```

```
Converge:

Get_template (resolution)
Sense (envelope)
if Match [t(r), s(x)] then
      Store_location
        { --> new envelope}
      Increase_confidence
      Increase_resolution
else
      Reduce_resolution
      Reduce_confidence
      if confidence < lost
          then Complain
            Restart
return
```

```
Construct:
Features (resolution)
                    { model --> internal_data(p_rel) }
Assign [internal_data(p_rel) --> model_loc(p_abs)]
return
```

Figure 2. Outline of localization algorithm

This system is currently being implemented on a PUMA 560 manipulator controlled by a MicroVax computer. The system has 3 different types of sensors: an ultra-sonic range finder, an array of 12 infra-red proximity sensors, and a 6-axis force wrist. The sensors are mounted on a bracket shown in figure 3. The characteristic differences in these sensors provide the variation in the sensory resolution. The shape and size of the *sensory scope* and the *uncertainty envelope* of their sensory data are different.

1) **The ultrasonic range finder** can detect a surface within a conic volume with range between .5 and 35 feet, within roughly 30 degree cone. The measured distance to the detected surface is accurate to 0.1 of an inch; however, the corresponding uncertainty envelope is large due to the angular signal spread and reflection.
2) **The infra-red proximity sensors** can detect surfaces from 0.05 to 1 inch away. Their scope is more cylindrical than conic. The reflectivity of the surface has significant effect on the measurements, and calibration is necessary for absolute range information. However, most important sensory data from the proximity sensors will either be on-off (as in edge detection), or relative measurements (surface orientation).
3) **The 6-axis force wrist** measures the components of the contact force. It can determine the position of the point of contact accurately. Its uncertainty envelope is spherical in shape, with its radius determined by the accuracy of the robot. The exact orientation of surfaces can also be derived from its data.

The sensory resolution is a function of the uncertainty envelope. Thus one can change the resolution by changing the sensor, and also by changing the sensing parameters--e.g. sensing direction. To illustrate, assume that the user provides the initial context envelope. Then the ultrasonic range-finder looks for any discontinuity in measurements within the envelope. This is our lowest resolution sensing. Once it detects the discontinuity, the robot moves the ultrasonic sensor in a path that will locate the approximate positions of the object's surface patches. This is our second level sensing. (Although we used the same sensor, the positioning of the sensor reduced the uncertainty envelope, and therefore increased the resolution.) Next, the proximity sensors are used as an on-off array to detect edges and corners in the vicinity of the observed surface patches. In the next level, the proximity sensors are used again, but this time, as individual ranging devices to acquire more accurate measurements of the surfaces bounded by the edges. Finally the tactile force data make the last refinement on the measurements. At this point, the necessary surfaces and edges are known with sufficient accuracy, and the *construct* process can proceed to build an interpretation.

Note that each level relies on the previous level's context envelope for efficiency of its sensing. Also, keep in mind that transformations are being performed on the internal model with each transition to provide the template for matching with the sensory data. Following is a list of the forms which these templates can take: {discontinuity cloud, edges, corners, surface patches [6], bounded surfaces, and coordinate-independent constraints [7]}.

STATUS

A PUMA 560 workstation has been allocated for this project. The control software is currently being installed on a DEC MicroVax in VAX C. The three sensory subsystems are now available for experimentation. The Barry-Wright force wrist has an on-board processor and electronics to condition and transform the data into 6 components of the contact force. It will interface with the MicroVax via serial ports. The data from the proximity sensors are conditioned at the bracket. The signals will input to an ADC board which plugs directly into the computer's backplane. The ultra sound system is controlled by a separate STD-bus system. The Polaroid-built transducer connects to a UDM interface board, and is controlled by a Z-80 processor. The sensor driver, written in Forth, resides in an on-board ROM [8]. The sensory information is transferred to the main computer via serial ports. We expect to publish concrete results from this experiment in the near future.

DISCUSSION

We have demonstrated how a localization process can benefit from the multi-resolution data structure. Recognizing that the world takes on different characteristics when viewed from a different resolutions, we constructed a sensing strategy that can extracts meaningful information from a very small number of measurements. Clearly, this multi-resolution sensing technique is not limited to localization. As mentioned, by enabling one to instantiate the universe at various resolutions, it will provide elegant solutions to many complex problems in sensing and machine intelligence. Modularity of the structure is another valuable feature of this technique. Each resolution level is a self-contained module, which complements the other levels. They are not constrained to any particular sensor or hardware, and innovations in sensor technology can be utilized fully without the need to reconfigure the entire system. This modularity also ensures that occurrence of failure at any one level is not catastrophic: with a properly designed software, only the efficiency should suffer.

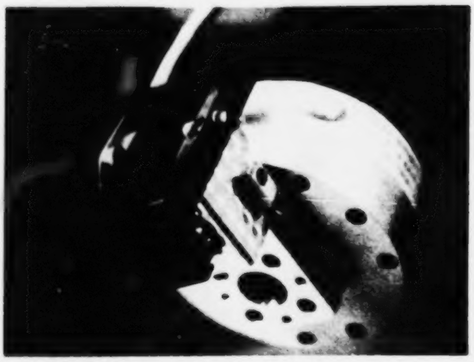


Figure 3. Multiple sensors. 12 infra-red proximity sensors, an ultra-sonic range finder, and a 6-axis force-wrist form the sensory system for the multi-resolution sensing.

Accordingly, multi-resolution sensing offers a robust, efficient, and cost-effective means of achieving adaptive capabilities. The approach is intuitive to humans. And the user's active role in the process should be psychologically satisfying and not burdensome. Therefore, the user should feel comfortable with it. Multi-resolution sensing promises to be a powerful and effective tool for the rehabilitative robotics.

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AUTOMATED ROBOTIC GRASPING BY USE OF OPTICAL PROXIMITY SENSORS

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ABSTRACT

The need for a smart sensate hand for rehabilitative robotics has been emphasized to minimize the degree of focused conscious attention required to use the robotic aid, to reduce fatigue and encourage user acceptance. A three-fingered hand with proximity sensors installed at each finger tip is considered for two-dimensional simulations, and different polygonal objects are tested. The results of the simulations indicate that the method is particularly effective for the symmetrical object. Actual experiment using a parallel-jaw hand which is equipped with 16 proximity sensors is conducted to verify the theory. And effectiveness of using the proximity sensors as pseudo-touch and -visual sensors for automated grasping is validated.

INTRODUCTION

The rehabilitative robotics is distinguished by the constant inclusion of a **man-in-the-loop** in which the user is expected to remain within a supervisory loop. Inside the supervisory loop, an operator occasionally sets sequences of subgoals and modifies its parameters. The operator's command is largely dependent on his visual perception which can be easily hampered by some reasons. For example, the operator will not be able to guide a manipulator to grasp a block in a box when the block is not visible to him; and when the object to be grasped is partially hidden by some obstacles in front of it; and even when the operator is assisted by the TV displays, he should overcome the lack of depth information apparent in the TV screen. Such deficient, and moreover non-visual information related to manipulator control is obtained from tactile, force/torque, and proximity sensors attached to the terminal device or arm mechanism.

Hand-Based Sensors and Grasp Automation

Hand-based sensors are defined as sensors which are attached to the robot hand. They provide such information on the local environment as relations between the object and the robot or the values of some characteristic parameters of the object (e.g., geometry, color, surface reflectivity, texture, and so on). The local environment concept was first suggested by Espiau [1]. And they are effectively used to command interactions with the world adjacent to the robot. In this case, the robot hand includes the final joint of the manipulator or the wrist as well as the end-effector itself.

To achieve a desired goal, the operation of a manipulator can be subdivided into two motion phases: **transport phase** and **terminal phase** [2]. In the transport phase, the primary concern is to move the terminal device (or end-effector) safely from one place to another, possibly also observing some constraints on the path and attitude of the terminal device during motion. In the terminal phase, there are three main concerns: to achieve an appropriate final position and orientation of the terminal device relative to an object or relative to a location in the work space; to obtain sufficient contact between terminal device and object; to generate appropriate handling force or torque at the terminal device for dynamically constrained tasks like inserting a peg into a hole, wiping a pane of glass, and so on. Once the desired object is recognized either by the controller of the manipulator or by the operator, the next stage of positioning and orienting the end-effector can be automatically processed by the reflex control loop based on the information from the non-contact hand-based sensors such as range or proximity sensors.

If the end-effector is successfully aligned with respect to the object, the problem of the stable prehension arises next. This kind of problem has been studied by Hanafusa and Asada [3], Jameson [4] and Cutkosky [5]. While there are abundant number of literatures on the grasp mechanism analysis in the kinematic and control point view, the actual implementation based on the sensory feedback from the end-effector seems to be difficult and not quite satisfactory. Most difficulties are incurred due to such inherent problems of the sensors themselves as sensitivity, non-linearity, noise, size-compatibility, etc. Hence the actual application of hand-based sensors on the manipulator control is limited by the current state of the art of sensor technology.

Among various hand-based sensors, optical proximity sensors are chosen to verify their effectiveness in accomplishing automated grasp task, since they are compact in size and provide useful pseudo-touch and -visual information on the local environment around the robot hand. A parallel-jaw hand equipped with 16 optical proximity sensors was developed. It has been used for grasping various objects automatically without operator's continuous attention and series of command.

OPTICAL PROXIMITY SENSOR BACKGROUND

Although inductive, capacitive, ultrasonic, and pneumatic sensors can be adopted for proximity sensation, the general trend is in the use of optical sensors. The optical proximity sensor consists of a combination of emitter(s) and receiver(s). The emitter is usually an infrared light emitting diode (LED) and the receiver a silicon phototransistor. The electrical signal given by the receiver depends on how much of the incident ray of the emitter is reflected back and detected by the receiver. Although the emitter-receiver configuration is dependent on the specific application, commercially available optical sensors are compactly packaged as emitter-receiver assemblies.

ADVANCED ROBOTIC AID PROJECT

The Veterans Administration is sponsoring a continuing effort to develop a robotic manipulation aid that can be controlled by severely disabled individuals to provide functional restoration of lost motor skills. The Veterans Administration/Stanford University Robotic Aid Project (VA/SU RAP) is ongoing effort to develop the second-generation Robotic Aid, and its goal is proclaimed as "From Feasibility To Utility [6]." The Advanced Robotic Aid Project is focused on the development or improvement of (1) human/machine interaction, (2) mobility, and (3) machine autonomy. A degree of autonomy is crucial if the Advanced Robotic Aid is to lessen the control burden and the degree of focused attention needed to complete a given task.

THEORY AND SIMULATION

Two aspects of the manipulation process are identified in machine autonomy. One is 'Strategic Functions' which refer to manipulative tasks that require some overall knowledge of the environment, and are preceded by a planning phase. And the other is 'Reflexive Functions' that result directly from sensory stimuli. The user's role is limited to initiating the functioning and monitoring its successful execution, if those functions are implemented properly on the robotic system. The Automated Approach/Grasp task fall into Reflexive Functions category. It includes object detection during grasping and collision avoidance during piloting.

The proximity sensor system can be applied for object detection and identification, obstacle avoidance, surface following, automatic tracking of a moving object, and search for optimal grasp positions. Although most of these applications are included in Automated Approach/Grasp process, search for stable prehension positions is a major issue of this study. A stable prehension position is defined on the object where the pre-defined grasp goal function is extremum (i.e., either maximum or minimum). The grasp goal functions can be potential energy of grasping or any predefined pseudo-potential functions.

A three-fingered hand with proximity sensors installed at each finger tip is considered for two-dimensional grasping examples. The three sensors are located on the "sensor circle" in the same distance. And it is assumed that the object to be scanned is initially inside the circle. If the proximity sensor gives exact distance measurement from the sensor to the object surface, then we may define the grasp goal function as a sum of inverse distances measured by each sensor with respect to a scanning angle. The quantity inversely proportional to the distance is estimated, since the signal from the proximity sensor is non-linear and monotonously decreasing with respect to the distance. Figure 1 shows one of the simulation results; a scanning process to find stable grasp positions on a quadrilateral. The first step is to find a centroid of the object through initial scanning, if perfect distance estimation is available. Then the center of the sensor (or finger tip) circle moves to the centroid of the object. And finally, stable grasp positions are determined through another 120° rotational scanning. The simulation results indicate that the method is particularly effective for the symmetrical object, since it tends to have less singular grasp positions and the static equilibrium conditions can be easily satisfied.

Another simulation using the parallel-jaw hand with two proximity sensors installed on each hand is under way to find optimal prehension locations on the object. By assuming a pseudo-potential function which can be determined through curve-fitting of the sensor output signal, it is not necessary to extract the distance information from the proximity sensor signal. Direct estimation of the grasp goal function with constraints to satisfy the static equilibrium is the next step of the research.

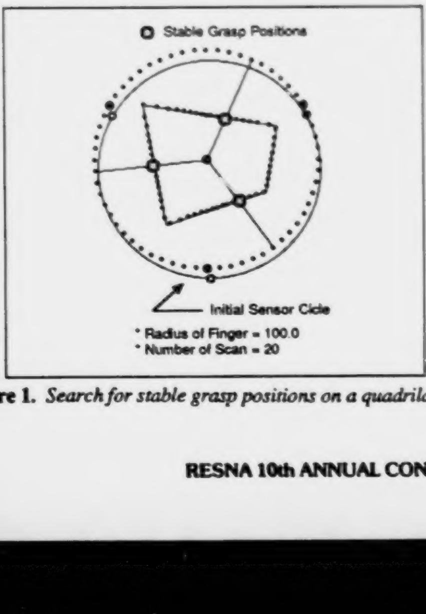

Figure 1. *Search for stable grasp positions on a quadrilateral.*

EXPERIMENT

The experiment has been carried out within the framework of the VA/SU RAP. And automated grasping test is performed by use of a parallel-jaw hand with 16 optical proximity sensors installed.

Blue Hand: Sensate Hand for Robotic Aid Project

The need for a smart sensate hand for rehabilitative robotics was discussed by Leifer *et al* [7][8]. They emphasized the main goal to minimize the degree of focused conscious attention required to use the robotic aid, in order to reduce fatigue and to encourage user acceptance. To fulfill the need, the Blue Hand is developed and 16 infrared emitter-receiver pairs are installed on fingers. Figure 2 shows a photograph of the Blue Hand. Most of electronic circuits for signal processing are located inside the hand. Proximity data from the optical proximity sensors are divided into 12 groups, that measure the proximity in 5 directions of the end-effector plus two orientations of the hand with respect to a surface. The hand is also equipped with a force sensing wrist to facilitate tasks such as placing a grasped object on a table and operating a push button. To integrate both proximity and force sensing, 'Integrated Sensory Perception' concept is being investigated by Park and Leifer [9].

Advanced Robotic Aid System Configuration

The hardware and software structure of the complete Robotic Aid system is described by Michalowski *et al* [10]. The Robotic Aid system is schematically shown in Figure 3. The real-time control software is written in MicroPower/Pascal language which provides for the breakdown of the application into concurrently executing processes. The software development system is a VAX 11/750 computer and the proximity sensor signal is processed by a KXT11-CA dedicated peripheral processor. The processed data is transferred to the main system memory via on-board DMA controller. This peripheral processor communicates directly with the target system (LSI-11/73) via the Q-Bus.

Experimental Results

Most manipulation tasks can be subdivided into series of motion elements (or primitives). By identifying each motion primitive and combining some of those motion elements, one complete set of manipulation task can be completed. This can be considered as a task-level programming. It is certain that

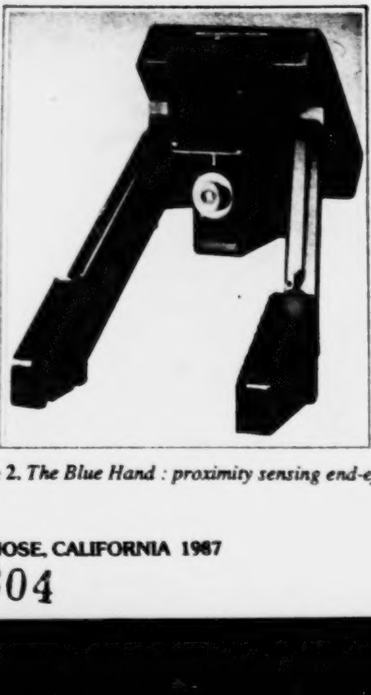

Figure 2. *The Blue Hand : proximity sensing end-effector*

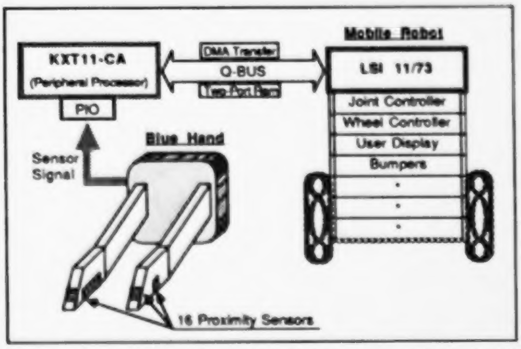

Figure 3. *System configuration of the Advanced Robotic Aid with the Blue Hand integrated.*

even such simple motion elements as object detection, placing an object on the table, and grasping a fragile object require some kind of sensory feedback. In other words, without a sensory feedback in the control loop, it is impossible to execute most of task-level commands. The Blue Hand is being used to identify and perform individual motion primitives and to accomplish the whole grasp automation process.

The following manipulation elements identified for the grasp automation task.

1) Object detection
 --> When the sensor detects an object, stop moving.
2) Surface detection and parallelism
 --> When surface detected, stop moving and align the hand parallel to the surface.
3) Centering the finger
 --> Center the finger with respect to the object before grasping.
4) Contour following
 --> Fly over the surface by maintaining the specified distance and orientation.
5) Object identification
 --> Scan around the object to notify an operator of the identification.
6) Search for optimal grasp position
 --> Scan around the object to find optimal grasping positions.
7) Gripping
 --> Close the fingers and grip the object with a specified pinch force if a gripping sensor is available.

Each element can be a unique one (i.e., a primitive) or a combination of other elements. Various strategies can be devised to accomplish each individual manipulation element. For example, "centering-the-finger" can be accomplished by three different ways. If we assume that the object has been already located between the fingers, the first method is: (1) move the hand to the left in the tool frame until the object is detected; (2) move the hand to the right until the other surface of the object is detected, and measure the distance travelled; then (3) move the hand to the left half the distance travelled. The second is: (1) move the hand to the left until the object detected; (2) close the finger while moving the wrist to the right and controlling the gap between the right finger and the object surface; then (3) continue to close and stop the wrist motion when the sensor readings of the left finger show the same as those of the right. The third one is the fastest: (1) close the finger; (2) when one of the finger detects the object surface, then follow the steps of the second strategy. The second and the third strategies require a reliable and fast position controller. In order to overcome the control stability problem, most of movements are done in slow speed.

CONCLUSION

As the robot interacts with the environment through its end-effector, automation of end-effector actions will significantly enhance the machine autonomy and is crucial to reduce the operator's work load. And it has been proved that through this study that the user can easily manipulate the environment by using the Advanced Robotic Aid which is implemented with multiple sensor-driven real-time reflex control loops. While many applications using the Blue Hand are still in development stage, it has been observed that automated grasping based on proximity sensing is performed reliably and promising. Even though the proximity sensor itself has some limitations, it occupies the unique position in the sense that it bridges and fulfills the deficiencies of the current vision and tactile sensing systems.

ACKNOWLEDGEMENTS

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NAVIGATIONAL ALGORITHMS FOR A MOBILE ROBOTIC AID FOR THE SEVERELY DISABLED

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ABSTRACT

The Rehabilitation Research and Development Center at the VA Medical Center in Palo Alto, in collaboration with the Department of Mechanical Engineering at Stanford University, is exploring the use of robots in rehabilitation. The range and ease of manipulation are enhanced by adopting the three-wheeled, omnidirectional motion base of La [1]. An analysis of the kinematic behavior of the motion base is presented here, along with some useful expressions that relate the motion of the individual wheels to the motion of the robot as a whole. The robot's onboard computer uses these expressions to control the direction of motion and the trajectory of the robot, based on spoken commands from the disabled operator.

THE ROBOTIC AID PROJECT

The Robotic Aid Project is an ongoing effort to develop a robotic device that could assist severely disabled persons in the performance of simple manipulation tasks that are associated with activities of everyday living in a homelike environment [2]. The latest version of the robot features a six degree-of-freedom robotic arm, equipped with a sensate gripper, mounted on a three-wheeled vehicle. The wheels are arranged along the sides of an equilateral triangle. A set of free-wheeling rollers is distributed along the circumference of each wheel, allowing the wheel to move freely in a direction parallel to its axis of rotation. Each wheel is driven by a dedicated DC servo-motor. An onboard LSI11/73 computer controls the turning motion of the wheels. As shown below, any instantaneous motion - an arbitrary rotation of the vehicle combined with a translation of the center of mass - can be achieved (within the limitations of the finite torque capacities of the motors) by selecting an appropriate set of wheel velocities. Thus, unlike conventional mobile robots whose wheels must be re-oriented before the direction of motion can change, the Robotic Aid has true freedom of motion in the plane. Besides the obvious advantage of great manouverability, the design makes it easier to treat the entire robot as a nine degree-of-freedom manipulation system, and to develop efficient algorithms for simultaneous motions of the arm and the vehicle.

In practical applications, the desired motion of the robot is usually expressed as a velocity vector (including a rotational component) or as a trajectory in the plane. Typically, the trajectory is defined as a parametric curve $(x(t), y(t), \theta(t))$, where θ measures the orientation of the vehicle and t denotes the parameter time. The robot's onboard computer [3] must be able to calculate three instantaneous wheel velocities based on the desired vector or trajectory. It should be noted that, similarly to other wheeled devices and unlike jointed manipulators, the total motion of the omnidirectional motion base during any finite time interval depends on the precise history of the wheel motions, rather than the total rotational increments of the three wheels.

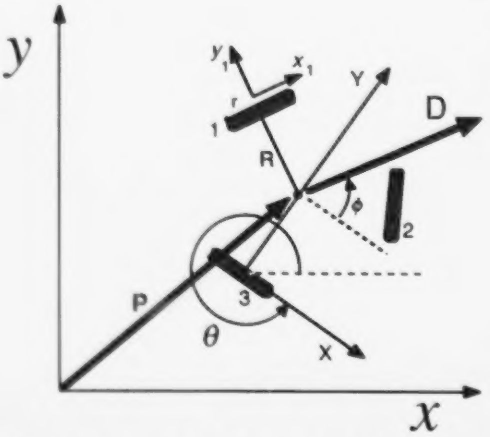

Figure 1: A top view of the omnidirectional robot base. The actual distance from the centerline of the robot to the wheel-floor contact point is $R = 10.0$ in. The wheel radius is $r = 6.0$ in.

ROTATIONS AND TRANSLATIONS

Figure 1 shows the arrangement of the wheels and introduces the notation. The coordinate axes $(\mathcal{X}, \mathcal{Y})$ define a fixed coordinate system within which the vehicle follows some trajectory. The (X, Y) coordinate system is fixed with respect to the vehicle. The two systems are displaced with respect to one another by the vector $\vec{P}$ and rotated by an angle θ. It should be noted that the numbering of the wheels, the alignment of (X, Y) on the vehicle and the designation of the Y-axis as the "forward" direction are all arbitrary. At any instant in time, the robot is rotating with angular velocity $\Omega = \dot{\theta}$ and simultatneously translating with linear velocity $\vec{D} = \dot{\vec{P}}$. The motion results from angular rotations of the individual wheels, ω_i, which are proportional to the rotation rates of the DC servomotors. In this section we consider the case of constant rotations and translations.

The simplest motion of the vehicle is a rotation about its vertical axis with constant angular velocity. It is clear that such a motion arises from all three wheels moving with the same angular speed: $\omega \equiv \omega_1 = \omega_2 = \omega_3$. The vehicle rotation is then given by

$$\Omega = \frac{r}{R}\omega \tag{1}$$

In the case of a translation with constant speed, it is convenient to introduce three coordinate systems (x_i, y_i) which are fixed with respect to the individual wheel locations such that each wheel rotates about its y_i axis. Since the base moves as a rigid body, the same velocity vector can be considered in the three coordinate systems: the x_i component corresponds to motion caused by the turning of the wheel: $d_i \equiv d_{x_i} = r \cdot \omega_i$. The y components, d_{y_i}, represent the unconstrained motions of the free-wheeling rollers.

In the (X, Y) system, the translational velocity is represented by a vector of magnitide D, oriented at angle ϕ with respect to the X-axis. Elementary decomposition gives:

$$\begin{aligned} d_1 &= D \cdot \cos(\phi - 60) \\ d_2 &= D \cdot \cos(\phi + 60) \\ d_3 &= -D \cdot \cos\phi \end{aligned} \tag{1}$$

We note the interesting fact that, for pure translations, $d_1 + d_2 + d_3 = 0$. Manipulation of the above equations also yields:

$$\tan\phi = \frac{1}{\sqrt{3}} \frac{d_2 - d_1}{d_3}$$

If $\vec{D}$ is expressed in terms of its components in (X, Y): $D_x = D\cos\phi$, $D_y = D\sin\phi$, then expansion of (1) yields:

$$\begin{aligned} d_1 &= \tfrac{1}{2}(D_x + \sqrt{3}D_y) \\ d_2 &= \tfrac{1}{2}(D_x - \sqrt{3}D_y) \\ d_3 &= -D_x \end{aligned} \tag{2}$$

The (x_1, y_1) system is rotated by 120 degrees with respect to the (x_2, y_2) system:

$$\begin{aligned} d_{x2} &= d_{x1} \cdot \cos 120 - d_{y1} \cdot \sin 120 \\ d_{y2} &= d_{x1} \cdot \sin 120 + d_{y1} \cdot \cos 120 \end{aligned}$$

By eliminating d_{y1} and noting that $d_{x1} = r \cdot \omega_1, d_{x2} = r \cdot \omega_2$, $D = ({d_{x2}}^2 + {d_{y2}}^2)^{\frac{1}{2}}$, we obtain:

$$D = \frac{2r}{\sqrt{3}}({\omega_1}^2 + {\omega_2}^2 + \omega_1 \cdot \omega_2)^{\frac{1}{2}} \tag{3}$$

The motion of the rollers is neither controlled nor monitored in the present implementation. Equations similar to (1) can be derived for the rolling motion. D and ϕ can then be eliminated to yield:

$$\begin{aligned} d_{y1} &= -\frac{1}{\sqrt{3}}(d_1 + 2d_2) \\ d_{y2} &= \frac{1}{\sqrt{3}}(2d_1 + d_2) \\ d_{y3} &= \frac{1}{\sqrt{3}}(-d_1 + d_2) \end{aligned}$$

These equations show that, for translations, the rollers will not move if the wheels are not driven (this is trivially true for rotations). Thus, in spite of the freely-moving rollers, the vehicle can be immobilized by "locking" the wheels. Interestingly enough $d_{y1} + d_{y2} + d_{y3} = 0$, always.

CONSTANT WHEEL VELOCITIES

The above considerations allow us to understand the motion of the vehicle if the three wheel velocities remain constant. Given three rotation rates $\omega_1, \omega_2, \omega_3$, we can view the overall motion as a pure rotation of magnitude $\Omega = (\omega_1 + \omega_2 + \omega_3)/3$, superimposed on a pure translation with individual rotation rates $\omega_i^{'} = \omega_i - \Omega$. The resulting trajectory is a circle of radius $D/2\Omega$, where D is given by (3) (the corrected values $\omega^{'}$ must be used). The circular motion is synchronous: a complete turn around the circumference is accompagnied by a full rotation of the vehicle about its verticle axis. Pure translation corresponds to the special case $\Omega \longrightarrow 0$, i.e. to motion along a circle of infinite radius.

In principle, constant-velocity motion provides a way of moving the vehicle between any two configurations in the plane, as shown in Figure 2. Given initial and final orientations, the three wheel velocities must be chosen such as to send the robot along the arc of a circle, with the angular interval along the circumference just equal to the desired change in orientation: $\alpha = \theta_2 - \theta_1$. The value of Ω is then α/T where T is the desired time in which the total motion is to occur. The initial translational velocity must be offset (by an amount β) from the straight-line path to the destination, so that it is tangent to the circle. Elementary geometry gives $\beta = \alpha/2$.

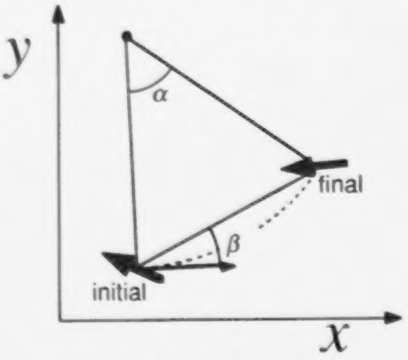

Figure 2: Motion of the robot along the arc of a circle. The thick arrows show the initial and final orientations of the robot. The change in orientation is α. The initial velocity vector for the curved trajectory forms an angle β with the straight-line path.

Although constant velocities are easy to implement with servo-controllers or stepping motors, the resulting trajectories are unacceptable whenever large changes in orientation are desired. It is possible, however, to approximate any trajectory by a series of small circular arcs. Within each arc, the wheels will move with constant speed and the simple expressions derived above may be used. The disadvantage of this scheme is that it assumes instantaneous transitions between constant rotation rates, i.e, short periods of very high torque. The scheme has been adopted for the Stanford/VA Robotic Aid, as outlined below.

TRAJECTORY MOTION

The basic iteration time for the servo-controllers of the Robotic Aid is 32 ms., which, combined with the rather small velocities that are needed in practical applications, allows us to use the constant-velocity approximation. To move the vehicle along a trajectory, the following steps are iterated every 32 milliseconds:

1. The current absolute position and orientation of the robot in fixed coordinates $(\mathcal{X}, \mathcal{Y})$ is assumed to be correct.
2. Based on some trajectory-generating algorithm, the next desired position and orientaion are computed. The new position is transformed into the robot's coordinate system (X, Y), using known values of $\vec{P}$ and θ.
3. In the (X, Y) system, a translational velocity (components D_x and D_y) is found that corresponds to a straight line motion to the destination.

4. The amount of rotation desired (which is the same in both coordinate systems) is halved and applied as a rotation to D_x and D_y. As a practical matter, we use small-angle approximations when rotating $\vec{D}$, since the angular displacement during 32 ms. is quite small. The magnitude of the vector is not corrected since the additional distance traveled due to curvature is insignificant.
5. Three wheel velocities are computed using (2). The velocities are sent to the wheel servo-controllers.

The observed performance of the above dead-reckoning navigation scheme is satisfactory over short distances (ten meters or so). In addition to the basic limitation of the constant-velocity approximation, a number of factors contribute to the overall uncertainty in the position and trajectory of the robot:

- Roundoff errors in the velocity computations.
- Peculiar shape of the wheels due to gaps between the rollers.
- Backlash in the gears and chain drive.
- Slippage of the wheels over the ground.
- Vertical motions of the robot.
- Uncertainty in the values of R and r.
- Finite resolving limit of the optical encoders on the motor shafts.
- Spurious torques due to angular accelerations of the rollers.

Because all of the above factors contribute to an accumulating error, there is a need to periodically sense the absolute location of the robot with respect to fixed objects in the environment. The Robotic Aid is being equipped with a laser-based scanning device that will provide absolute position updates.

ACKNOWLEDGEMENTS

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DESIGN OF A SECOND GENERATION DESK-TOP ROBOTIC AID

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ABSTRACT

A voice controlled robotic workstation for the severely disabled has been assembled, using an IBM PC/AT as the metacontroller. The PC oversees the operation of a Unimation PUMA 260 robot, as well as several other household devices. The system's status is indicated in two ways. A color monitor provides visual feedback, while audio prompting and feedback is provided by a VOTAN voice unit. The VOTAN also recognizes voice commands. The control programs for the IBM PC are implemented in Turbo Pascal. These programs allow for activation and control of a BSR X-10 environmental control unit (to operate lights, appliances, TV, etc.) and a telephone, in addition to the robot. Low level robot tasks are written in VAL-Plus, a robot control language supplied with the PUMA. The IBM initiates these pre-programmed tasks in response to the user's voice commands and allows real-time piloting (guiding the hand by voice control - i.e. emulating the teach pendant) of the robot using voice commands. The tasks performed by the robot were designed to adapt easily to different users. Currently, these tasks include: Brushing teeth, shaving, and cooking simple meals in a microwave oven.

INTRODUCTION AND BACKGROUND

The clinical evaluation of a stationary robotic aid is a branch of a larger robotic aid effort being undertaken by the Veteran's Administration and Stanford University. A more sophisticated mobile robotic aid is currently under development at Stanford. The ultimate goal is to develop an aid "that can be controlled by severely disabled individuals to provide functional restoration of lost motor skills" [1]. So far, only the table-top versions of the robotic aid have been tested in the clinical environment [2]. The first generation of the clinical robot incorporated a PUMA 250 robot with a ZILOG Z-80 controller. That system demonstrated the utility of a voice controlled robot by performing functional tasks at a fairly low level. For instance, robot positions could be labeled by the user , and then the robot could be commanded to move to those points. Simple pre-programmed routines could also be executed. Some of the problems with that system were due to the limitations of the hardware available. Speech recognition, and both visual and speech feedback were poor. In addition, the labeling of points was clumsy and used a vocabulary which was neither intuitive nor colloquial [3].

Our goal was to incorporate improvements in computer and speech-recognition technology into a new workstation with a library of pre-programmed tasks, more sophisticated controller logic and an improved user interface.

METHODS AND MATERIALS

The robot workstation consists of the PUMA 260, a refrigerator, microwave oven, and a rotating kiosk as shown in Figure 1. The kiosk holds the various items for the robot to use in performing tasks (i.e. - toothbrush, shaver, etc.). A block diagram of the system is shown in Figure 2.

Robot Programming Features

The robot tasks are programmed for safety and flexibility. A typical task is that of feeding soup. When the robot moves the soup spoon to the patient's mouth the movement is made at an especially low speed. This provides safety and reduces the patients apprehension. The position of the soup spoon for the patient to take a bite is set once at the beginning of the task. It can be repositioned at any time during the task. This feature

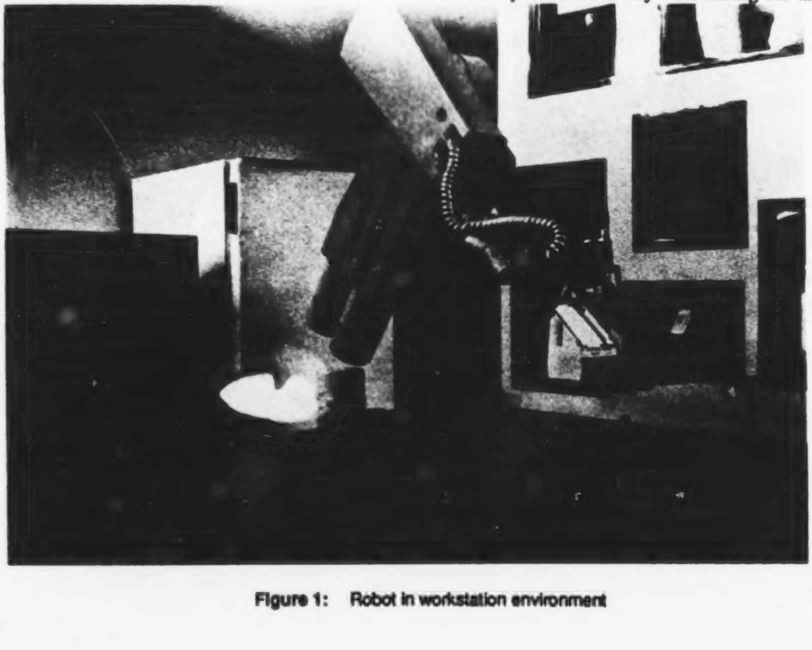

Figure 1: Robot in workstation environment

allows different patients with differing wheelchair heights to use the robot with equal ease.

Controller Programming Features

The controller program on the IBM PC/AT not only acts as interface to the PUMA controller, it also has its own built in logic and safety features. For instance, before a task can be initiated the IBM queries "Are you sure?" to guard against misrecognized words; when piloting is to be performed during a task near the patient's face, the IBM has the robot move in short incremental steps. In addition the controller logic prevents the initiation of conflicting tasks (i.e. trying to hold more than one object), and allows for the robot motion to be stopped at any time. Finally, the software is capable of taking data while the patient is using the robot so that performance times and other information can be gathered.

User Interface Features

There are two aspects to the user interface. The first is the commands available to patient. In this version of the workstation we attempted to use words which are meaningful to the patient. Tasks are initiated with task names, direction names for piloting are with respect to the patient (i.e. - right, left, up, down), etc. The second aspect is the feedback from the controller to the user. Each command, and prompts (such as "Are you sure?") are "spoken" back to the patient. The previous ten or so commands are also printed on the color monitor for the patients information. The color monitor also prompts the user with a list of possible commands for the next step in the task that they are executing. This prompting display changes dynamically as the task progresses.

For example, you might see a dialog of the following nature:

Command	**Response**	
Spoon	Spoon... Are you sure?	(Spoken by VOTAN and printed on color monitor)
Forward	*Forward* What?	(Written on screen, not spoken) (Expects "Yes", "No", or "Stop")
Yes	Yes	(Spoon is brought to person)
Forward	Forward	(Person positions spoon in front of mouth using step commands)
Up	Up	
Left	Left	
Proceed	Proceed	(Spoon is positioned above soup)
Use	Use	(Scoop soup, bring to mouth)

RESULTS AND DISCUSSION

Our experience with the new robotic aid indicates that improvements in computer and speech recognition technology in the past five years have allowed a tremendous improvement in the capability of the clinical robot system. They have allowed us to use a much more intuitive vocabulary - picked more for user comprehension, than to ease the job of the voice recognition system. The tremendous increase in microcomputer power available for a reasonable price has allowed us to implement a much more sophisticated control program, including the user prompting, which greatly reduces the learning time necessary to use the system. Unimation has also made many improvements in the PUMA 260 compared to the model 250. It is extremely difficult to disrupt the 260's operation badly enough that the robot has to be re-calibrated by an able-bodied person; we have not yet had this happen. The model 250, on the other hand, would require a manual recalibration whenever it hit an object and occasionally when it reached a joint limit stop. The 260 will, of course, stop if it hits something, but so far, we have always been able to recover from the problem without manually replacing the robot in its calibrating fixture. Finally, we have attempted to design the robotic aid as a complete system, with a suitable division of labor between the controlling computer and the robot controller. This helps the consistency of the user interface and the overall reliability of the system. The end result of these improvements is that we are now able to have patients accomplish tasks of daily living in approximately two - three hours of training, while reaching a comparable level of ability with the first generation system would have required seven or eight hours of training.

CONCLUSIONS

In moving from the first to second generation robotic aid workstation great strides have been made in the robustness and utility of the workstation. This has been partly due to the advances made in the quality of the components used in the system, and this trend will undoubtedly continue. Improvements have also been brought about by programming with an eye toward safety, flexible executions of tasks, and logical progression through tasks. Furthermore, greater attention has been paid to the user interface, making the user's language more natural and the feedback more understandable.

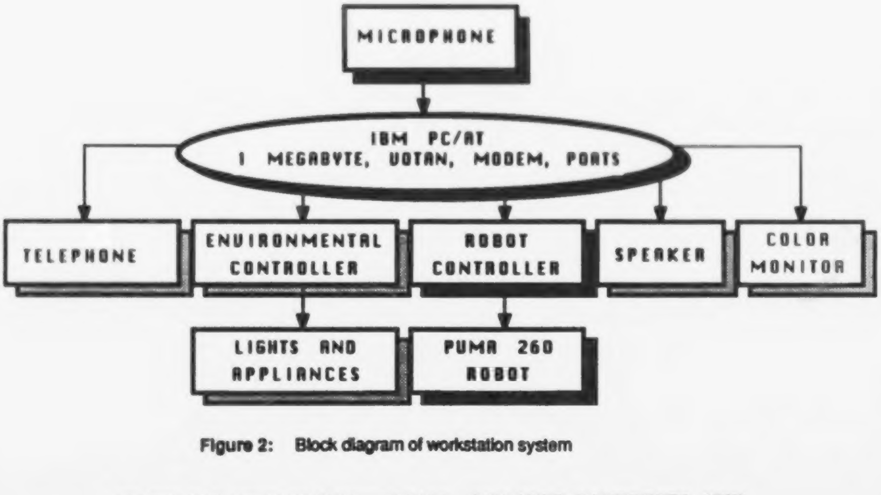

Figure 2: Block diagram of workstation system

Based on our experience with the robot workstation we have assembled, and the continuous improvements being made in robot technology we foresee a robot system which is available at reasonable prices, from off-the-shelf components. To this end we will be looking into the use of comercially available prosthetic end effectors on the robot. On the software side, we hope to make the system even more independent of outside aid. We hope to develop a system for user written robot programs. Also, we want to give greater freedom to the user in manipulating the IBM. The user will also be able to retrain vocabulary words, or add to the vocabulary list while operating the robot.

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Task Analysis for the Use of Robotic Manipulators

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ABSTRACT

A process has been developed for analyzing and specifying vocational tasks that could be performed by a disabled person using a low cost robotic manipulator. It consists of a number of phases based on current industrial robotics application planning and time-motion analysis. In addition to providing a means for making decisions about a potential task's appropriateness, this process also helps in defining system configurations and adaptations to the vocational environment. Although this process has been designed for vocational applications, it could be applied to any manipulator applications such as self-care.

INTRODUCTION

The application of robotic manipulators to aid physically disabled people has evolved significantly over the last 15 to 20 years [1,2]. Decreases in computational price/performance as well as other technological advances have provided the opportunity to extend robotics into many new application areas. Central to this progress has been a shift from direct manipulator control modes to efficient modes that combine direct and autonomous control.

The Rehabilitation Engineering Center at Tufts-New England Medical Center has been involved in a project to demonstrate the application of small inexpensive robotic manipulators to vocational environments [3]. A major component of the initial work was the creation of a development environment for task execution as well as the development of some general purpose applications programs for assessment and training. With these tools in place it is now possible to find vocational situations where a robotic manipulator could provide assistance to a potential employee who is disabled.

It has become apparent that there is a need for a method for determining whether or not a potential job is appropriate for a person and robot assistant. Although in some situations it is possible to intuitively evaluate the application potential, there are many cases where the complexity of a potential application warrants the use of an analytical tool. In addition, a task analysis tool can provide information as to engineering and adaptations necessary to place a potential user and target manipulator in a job.

ROBOTICS VS. TELEMANIPULATION

Although the terms *Robot* and *Robotics* have become common-place in the rehabilitation field, it is appropriate to consider many of the tasks inherent in an application as telemanipulation. Telemanipulation is considered to be direct user control over the manipulator's actions, while robotics is considered to be autonomous action through indirect control (e.g., programming or teaching). [4]

Pure robotic applications are inappropiate for disabled people because they are generally autonomous in nature and user interaction is usually intervention when failure occurs. An example of this would be a manufacturing assembly operation. On the other extreme, pure telemanipulation applications are inappropiate because they generally require unimpaired physical function of the user.

Book [5] describes six categories of telemanipulator control modes. The highest in the hierachy is called *Supervisory Control* that is described as a control mode which:

> ...allows the operator to specify some of the desired motion symbolically instead of by analog. The computer interpreting the symbolic commands then issues the joint commands. This mode of operator interface results in a hybrid between teleoperator and robot.

This method of control is most appropriate for rehabilitation applications using current low-cost technology. While typical telemanipulator applications involve work conditions that are inappropriate for humans (e.g., handling of radioactive materials), telemanipulators can enable disabled people to access jobs normally performed by unassisted able-bodied people.
Appropriate telemanipulator applications tend to exist in highly structured environments where direct positional control of the robot is minimized. In addition these *good* generally present demands that make a pure autonomous robots solution inappropriate. Factors that create this situation that we have observed are:

- Need for social interaction
- Need for judgement (e.g., sensory or action planning) that is beyond current technolgies
- Need for judgement that is technologically achievable but not cost effective for this particular application

BACKGROUND

Task analysis procedures have existed as long as industrial robots. In fact, task analysis (a simple one page form) was used in 1956 by the then newly formed Unimation Corporation to determine the market potential for the yet-to-be designed Unimate robot [6]. As industrial robots have become more sophisticated, so have the processes used in application planning. Tanner [7] describes a 5 step process for analyzing potential sites for robotic installation:

Initial survey - Selection of candidate tasks that might allow robotic applications
Qualification - Decomposition and analysis of tasks with respect to a set of environmental and performance criteria
Selection - Selection of operations that will be feasable for robot implementation
Engineering - Selection of robot and design of the systems environment including robot placement, software and additional hardware (e.g., part feeders)
Implementation - Placement of manipulator, software and hardware

Within each of these steps, further breakdowns and analyses are used to reduce the complexity of potential applications. In addition, work has been done to extend *time-motion analysis* techniques to industrial robotics to provide more quantifiable task analysis tools [8].

Task analysis has been addressed in the rehabilitation field as well. Leifer [9] suggests eight attributes to use in the consideration of tasks. These are Commands, Controls, Communication Management, Autonomous Planning, Grasp, Manipulation, Programmable Reflexes, and Mobility. The intent of his analysis is to provide directions for research and design considerations for future robotics development. This paper, in contrast, addresses a task analysis process that has been designed and applied to current low-cost manipulators.

THE PROCESS

The basic process is to decompose a possible job into small modules that can be compared to a standard set of task attributes. Figure 1. shows a diagram of the process which has five major functional components. The figure shows a partial view of the process in terms of branching at each component. For example, Job Function Decomposition produces a set of tasks shown by the first set of branches. The subsequent procedures are applied to each of the outcome tasks. In addition, feedback loops allow redefinition and analysis of the application to occur.

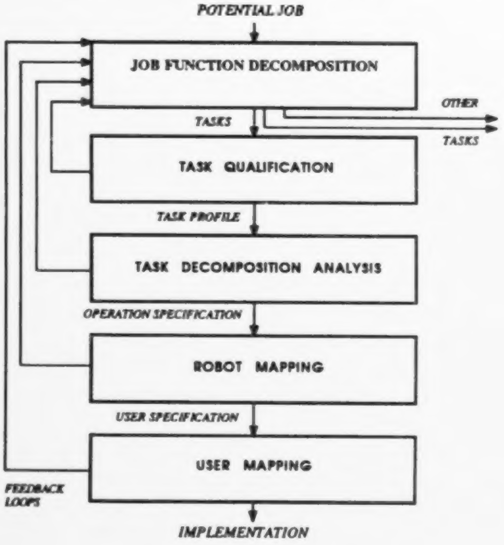

Figure 1. The Task Analysis Process

Job Function Decomposition

The purpose of the job function decomposition is to break a job into a set of independent tasks. In many industrial robotics applications, this has already been done in the existing setting (e.g., assembly line). For the purposes of this process, a task is defined as a sequence of dependent operations that are in general non-preemptive. For example, reading documentation would involve a series of operations that the user would prefer not to interrupt. Each of the resulting tasks from this process is subject to the subsequent steps of this analysis (shown in Figure 1. as additional task arrows).

Task Qualification

Task Qualification provides a general analysis of the task based on a set of task criteria. This step is a formalization of previous intuitive analysis performed in the project. The list of principal task criteria consists of three major areas:

- Environmental Requirements
  - Working Envelop
  - Repeatability of Locations
  - Number of Locations
  - Accuracy Requirements of Locations
- Object Requirements
  - Uniformity of Objects
  - Number of Objects
  - Physical Attributes of Objects (e.g., size, weight)
- "Intelligence" Requirements
  - Visual Discrimination
  - Abstract Judgements
  - Social Interaction

The result of this phase is called a task profile which consists of a set of task criteria scores for a particular task. Some of these scores are quantitative measures (e.g., working envelop) and some are relative ranked scores (e.g., abstract judgement). This profile will present certain indicators of the probable success of a task. In many cases a task will be rejected, or changes to the task will be considered.

Task Decomposition

This stage provides a more detailed examination of a task through further decomposition. Each task is broken into a sequence of component actions and decision branch points that occur in the normal execution of the task. This results in a diagram that resembles a software flowchart. The decomposition is accomplished through observation of an able bodied employee performing the task and also includes measurements of the time needed to perform each action. In addition to the measured completion times, acceptable completion times are estimated. This is done because there are times when a human operator may complete an action much faster than is necessary. This phase is the first step in a time motion analysis and produces a list of required actions and the necessary requirements for its execution.

Robot Mapping

The specifications of a manipulator are then examined with regard to the task requirements produced by the previous phase. Although the figure shows a single step to the process, it may be executed repetitively with a number of available manipulators. The primary concerns with regard to the manipulator are its dynamic performance characteristics such as speed of movements, accuracy and repeatability. If an appropriate manipulator is identified, then a set of user specifications are produced. These specifications include the degree of manual control required as well as other user requirements that may have become apparent in previous phases (e.g., vocal communication).

User Mapping

Finally, a user (or user model) is evaluated with respect to the needs inherent in the task operations. One of the major factors in this consideration is how much manipulator action can be performed by command initiated autonomous control vs. direct control over positions. This factor is largely determined by the degree of environmental structure. In addition, since there are a variety of computer interfaces available, they must be considered in conjunction with the user. This phase, like the previous one, will often be repetitively applied to different users and different interfaces. The outcome of this phase will be a final decision about the appropriateness of the task and specifications for the system, if it does, in fact, seem appropriate.

Feedback Loops

One of the most important aspects of this process is the presence of feedback loops along every step. Feedback loops provide the opportunity to redefine the job in terms of its necessary tasks and/or component actions. Although sometimes task redefinition is not possible, in many cases slight accomodations can remove *bottlenecks* from a potential automated application. In addition, feedback loops can allow creative engineering solutions to be applied to the environment or the task itself. For example, in many cases simple positioning jigs will significantly increase the structure of the environment and consequently increase the efficiency of a user/manipulator action.

CONCLUSION

Several of the tasks that have been previously considered by project staff members have been analysized with this process. The results have been consistent with *human* decisions. In addition, it has been found that in some cases, this process would have pointed out potential problems in implementation that were previously unanticipated.

One factor that has consistently shown to be a strong influence on task appropriateness is *Social Interaction*. Increases in sensing capabilites and advances in machine intelligence can not replace this *human* element. This fact makes the application of robotic manipulators promising in the service industry. Since this is the fastest growing employment sector it is hoped that new opportunities for disabled people will arise [10].

Finally, current work is directed towards refining this model and fully implementing it within the project. To a large extent this process is a formalization of three years of experiences within the project. It is hoped that as robotic manipulators become a *standard* clinical rehabilitation device, this process will allow less experienced clinicians and engineers to make good decisions and implement effective systems.

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CALVIN: New Perspectives on a Robot Language

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ABSTRACT

Since the initial report describing the development of Calvin, this robot control language has undergone substantial evolution in response to feedback from the two clinical sites. The evolution included such developments as improved screen control, clearer and more visually controllable error messages from the parser and enhanced controller-PC communications including continual communications and robot status checks. In response to the need for more complex programming strategies and such issues as Calvin's interpreting speed, variable type limitations and the need to keep Calvin simple, the library of robot-specific drivers (written in C) was revived, thereby accessing the full scope of C programming flexibility and power.

INTRODUCTION

Any rehabilitative robotics device, in order to be effective, must begin with the needs of the target population [6]. Furthermore, in rehabilitative robotics, systems have to avoid being specific to any single task or use since human need spans a broad spectrum [1]. In 1985, the inability of manufacturer provided software to meet the needs of a disabled person prompted the development of Calvin. Calvin was designed to be a rehabilitative robotics programming environment that would be a useful programming tool as well as a good robot training tool for persons with a wide range of training and backgrounds. In order for the language to fulfill both of these functions, five goals were established to guide the development process [8]:

- Calvin should be simple yet flexible enough to be usable by and useful to clinicians, application programmers, researchers and the disabled users themselves.
- Support for additional interface peripherals and sensors should be extensive and easy to implement.
- Calvin should be compatible with a number of candidate robots.
- Calvin should support and simplify the interactive development of interactive tasks.
- Calvin should be structured so as to create readable and maintainable code.

By the summer of 1986, Calvin had addressed and met the general design specifications indicated by the goals and was ready for trial in a clinical applications setting. Before reporting on the results of these trials, however, a brief review of Calvin as it appeared in 1986 is in order. Calvin is primarily a robot level programming language which incorporates elements of robot guiding [7] in a development environment. Calvin is an interpreter capable of accepting command line instructions or reading a file. In this respect, it has similarities to EARL [4] and RoboTalk [9]. The version of Calvin used on the Scorbot in 1986 had approximately 75 primitive functions which fell into four general categories: program flow control, mathematical and trigonometric, peripheral or I/O, and the robot specific drivers. In addition to these functions, however, Calvin's power and flexibility derive from its ability to accept user defined functions that combine these basic primitives with each other or with other user defined functions. This feature, patterned after the C programming language, makes Calvin a powerfully vertical language that can be used at any level, from position control to task level programming [10], depending on the complexity of pre-defined functions. Unlike C, however, Calvin can access and execute any of these defined functions independently and does not require a central *main()* function. Finally, Calvin does not have the variable naming restrictions of C, which allows a programmer to create function names which clearly specify what the function does. These features combine to meet the first and fifth goals of the guidelines.

Calvin's interpretive structure fulfills the fourth goal by creating a programming and user environment that directly links the robot with the programmer or user. Functions can be designed and tested immediately, and altered quickly. Individual functions can be rewritten and interpreted without re-interpreting or *parsing* an entire file.

Finally, the second and third goals are fulfilled by the modular internal structure of Calvin. The various primitive functions are easily altered, or replaced. The robot-specific drivers are intended to be assembled as a library that can be linked with the interpreter at compile time. With a variety of libraries on hand, Calvin can be adapted to another robot simply by re-compiling and linking the appropriate library. The same holds true for peripheral devices. By linking a library with drivers for speech synthesizers, joysticks, CRT control or digitalized tablet inputs, Calvin can easily be extended to alternative input and output strategies.

CLINICAL EXPERIENCES

Since the summer of 1986 the principal application has been a sorting task. This task is common to pre-vocational settings and addresses programming issues faced in rehabilitative robotics. The environment is fairly structured but still retains elements of unpredictability, such as the precise location of each piece to be sorted. This leads to the need for developing a balance between direct control over the robot and pre-programmed routines to speed up the task execution time [5]. There is a need for a huma decision process that will effect the robot's course of action, such as deciding where to put the piece selected o what to do if several pieces were accidentally picked up. Finally, in order to be effective in a wide range of sortin tasks with various students, certain aspects of the program needed to be easily adjusted, such as the speed o the robot, the manner of selecting target bins, the location of the target bins, and so forth. With the flexibility of Calvin, the development of the sorting program wa relatively quick and a second application was conceived.

This second application was a switch assessment program developed in response to the needs of the student population at one of the two clinical sites. Initially, the ver sight of the robot in motion was frightening to these students. There was a clear need for very basic exposure an training that would acclimate them to the robot and t begin to teach them how to control it. A switch assessment task was written which prompted, via the monito for a specific switch to be pressed and then recorded successes and failures and response times. Successful switc closures were rewarded with a robot dance, which gav the students exposure to the robot moving as a respons to their decision making activity. The program was designed to print a report of the students progress when the specified number of trials was complete, giving a physical therapist feedback concerning possible switch sites. The development of these applications and the feedback from the clinical sites revealed a number of ways in which Calvin could be further improved.

Screen Management
One of aspects of creating a useful and usable system which needed further development was Calvin's screen management capabilities. Few robot languages have developed this area well, but experience at the clinical sites demonstrated the need for visual feedback for the user. Given a population with some cognitive involvement and with vision impairment, the most effective way of presenting information regarding the robot was to create meaningful symbols large enough to be seen.

Error Detection, Correction and Reporting
Robot operations, particularly those in a rehabilitation environment, are subject to uncertain and often unstructured environments. Therefore, a large part of robot programming involves error detection and correction [7]. This is especially true in an interpretive or interactive environment. The user must be presented with clear error messages that indicate what has gone wrong. In addition, strategies must exist for error handling without recourse to restarting either the system in general or the specific task being executed, since these are not normally viable options for a disabled user.

Calvin's error handling, prior to modification, was limited to reporting the error by printing a message at the current cursor position on the CRT and terminating execution of that particular function. This was an acceptable solution when a single primitive function was entered on the command line and executed by Calvin, but as an error handling strategy within a Calvin program it fell far short of what was needed for a versatile and effective system.

Speed and Capability vs. Simplicity
A third area of concern involved a tension between the efficiency of Calvin and maintaining a simple, clinical environment. In the interests of simplicity, many of the more demanding and complex aspects of C were omitted from Calvin, including variable type declaration, structure declaration and the need for a line terminator. Calvin defaults all variable types to double precision and all variables are global. It allows no array declaration with the exception of one-dimensional integer arrays that can store ten elements and are used to store position values. It recognizes string variables and provides string management functions, but these variables do not have the array structure common to C strings. The core C flow control statements have been incorporated in Calvin, but in the interests of simplicity, the *switch*, *do* and *goto* statements have been omitted. Finally, the form of the *for* statement has been limited and does not allow multiple initialization or incrementation within the statement.

These simplifications make highly complex and extensive applications more difficult For instance, functions have to be written which mimic a two dimensional array and take longer to execute at run time, and longer to interpret when Calvin is parsing a file. The lack of privacy in variables can make it difficult, in large applications, to maintain the integrity of variables. Creating more and more C like capabilities for Calvin, however, would defeat the purpose of developing a simple, user friendly robotics environment.

The final limitation of Calvin is that it is not a compiler, it is an interpreter. Calvin does not produce executable code. An application that runs successfully today will need to be interpreted tomorrow. For large scale applications, this can become tedious and inefficient.

REACTIONS AND DISCUSSION

Each of the limitations presented above represents an extension of or complication to one or more of the already existing goals, and each needed to be responded to in the development process. For some of the complications, the response was fairly straightforward and opened the way for further refinement. For others, the response required a new approach, a new twist to the development.

Screen Management
Calvin's modular design made adding better screen control features a reasonably simple process. New screen control drivers were written using standard libraries and were added to the module for peripheral devices. Calvin can now manage variable size text (40 or 80 column) on several video pages in a variety of colors, including flashing and non-flashing characters on variable backgrounds. Using an alternative print command, a Calvin program essentially has full cursor control and can even paint an entire video page before displaying it. Although there are no real graphics capabilities, Calvin has use of the ASCII extended character set and can mimic some simple graphics. These added features immediately improved the students' ability to use the software.

Error Detection, Correction and Reporting
Improving Calvin's screen management capabilities produced a conflict with the way error messages were displayed. Carefully painted screens were often partially overwritten when the environment transmitted an error message. Although more time consuming to implement, Calvin's modularity again makes the solution an essentially easy one. All messages from Calvin are now handled by a single function which prints them on the last line of the current page. When preparing a screen, the user need only know to avoid the bottom line of the screen to maintain screen integrity. Status or error messages remain in place until a new one is printed or the status line is cleared by the user, and the user has the option of suppressing all error messages.

Actual error detection and correction within an interpreting environment is a more difficult problem. Errors that occur are real time and space errors such as loss of communication with the robot manipulator, jammed motors, attempts to reach a point beyond the physical reach of the arm or the accumulation of error factors in inverse kinematic conversions. When these errors occur during the execution of a program, recovery can be difficult. In Calvin, a special status flag was installed which is toggled *on* whenever an attempt to send a command to the controller fails, or when a request for information from the controller returns garbage. Each robot primitive was adjusted to return a status value to indicate if the communication with the robot was successful. In addition, each command that results in motion returns control to the computer immediately after sending the command string to the controller, allowing the user to select, design and implement an error handling routine of their choice. The errors resulting from inverse kinematic calculations were dealt with internally using an error value buffer which was included in and updated by each subsequent calculation.

Speed and Capability vs. Simplicity
The problem of keeping Calvin simple, able to perform complex applications tasks led to the revival of the independent C library of robot drivers. It became clear that complex applications were not only beyond the scope of what Calvin was intended for, they are also beyond the scope of what the average clinician, parent or employer is

capable of programming. These applications require development by a trained and competent computer programmer using a powerful programming tool. Since Calvin itself is written in C, the revival of the C library of robot drivers, linked with a specific application written in C, was the most obvious solution.

This development, however, gives rise to the question of the relationship between Calvin and the C library of functions. Although the languages are similar, Calvin code cannot be compiled by a C compiler. There are some serious syntactical and usage differences, such as the use of semi-colons as line terminators and the differences in variable declarations, which would prohibit the compiling of a Calvin program. Several approaches to this have been proposed and are being considered.

The first solution is to create a translator which would accept a Calvin file as input and generate the syntax conventions appropriate for a C program. This would allow a programmer to create and test programs using Calvin, and then translate and compile them into faster executable code. The main drawback to this approach is that Calvin's limitations will simply be transferred to the executable C file, solving the parsing speed problem, but not doing much to alleviate the data structures limitations and execution speed. Variable privacy, non-existent in Calvin, would be likely to result in compiler errors.

The second solution is to encourage the use of a standard C interpreter with the C library, thus allowing a programmer access to an interpreting environment yet retaining full use of the C conventions. The primary drawback to this solution is the quality of current C interpreters. One major limitation of commercial interpreters is their inability to execute any of the individual functions in a given file independently. Calvin, meanwhile, allows immediate the execution of any user defined function, making development far more modular and simple.

An additional point should be stressed concerning the use of a C interpreter. It would seem a reasonable possibility to replace Calvin with a commercial interpreter, thereby eliminating the need for compatibility between Calvin and C. This solution, however, would violate the first goal and one of the guidelines [3] used in developing Calvin, namely that the system be simple and usable by a wide range of users. A C interpreter requires the user to learn C and develop fairly sophisticated programming abilities.

The third, and perhaps most promising approach, is to enhance Calvin to allow C syntax conventions, but make those usages optional and transparent. All variables would default to double precision, but alternative variable declaration would be accepted. Calvin would recognize but ignore semi-colons as line terminators and comments could be restructured to be more C like. This approach retains Calvin's simple structure for clinical use, but allows more advanced programmers to do preliminary programming in an environment using code that is C compatible, and then move into the more usual C cycle (edit, compile, test, edit...) when the program's needs exceed the capabilities of Calvin. It also allows the programmer to use Calvin's ability to execute individual functions without a *main()*.

DOCUMENTATION

Work has been progressing on the development of documentation for the software package. Since Calvin's basic syntax conventions as well as a core of basic primitive functions, is intended to remain consistent across the various versions, a single user's manual is possible and the first draft has already been written. Appended to this manual would be a glossary of the functions included in a robot-specific library, such as the library of drivers for the Scorbot, and a glossary of additional peripheral drivers. Thus Calvin packages, both software and hardware, could be tailored to the specific application needs of a given environment. Preliminary drafts of the glossaries for the RTX and the Scorbot have been written and are in the process of being further refined.

CONCLUSION

Calvin has been under development and has been tested in clinical environments for over two years. Versions currently exist for the RTX from Universal Machine Intelligence and the Scorbot ER-III from Eshed Robotec. Both in theory and in practice, Calvin has proved itself a viable and effective rehabilitative robotics tool, and has provided a theoretical model for other rehabilitation applications [2]. As the issues relating to creating compatibility between C and Calvin while retaining Calvin's ease of use are further developed, and the Calvin library is extended to other manipulators, it is likely that Calvin will make a significant contribution to rehabilitative robotics.

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WORKPLACES FOR THE HANDICAPPED IN FLEXIBLE PRODUCTION AUTOMATION WITH ROBOTS

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ABSTRACT:

The use of robotic equipment in rehabilitation is of a quite different nature than in industrial production. A characteristic of the use in rehabilitation is that there is an intensive interaction between the human and the robot. This turns the system basically into a manipulative system, for example, as they are used in nuclear environment and space technology. The philosophy of underlying feasibility project is to use the unique capability for interaction of the (disabled) worker in an industrial production environment. The most important parts of this interaction process are the human senses and intelligence. Both are either sometimes too difficult to model and transform into a safe working technical system, or it will be too expensive with present technology.

This means that sometimes a (handicapped) worker can have a task within the cycle of robot operations. This might be a task which is impossible to do for a machine or cannot be done reliably and inexpensively.

This project has developed a demonstration work cell using a Universal Machine Intelligence RTX, 6 d.o.f. manipulator under the control of an IBM AT microcomputer.

PROBLEM DESCRIPTION:

If one has to deal with a severe functional impairment, it turns out that many jobs and many tasks in industry cannot be done anymore. Striving for job opportunities for disabled people, most research goes into the field of office jobs, often in combination with computerization. The problem of a gap between functional possibilities of a disabled worker and job requirements can sometimes and partly be solved by adapting the work environment or/and giving the worker special tools.

A quite different approach is to create new tasks and jobs which are in a good agreement with the handicapped person's functional capabilities. This project deals with this approach and has focussed the attention on a new category of work: i.e. work to be done around industrial robots. This should not be confused with most of the robotics research as it is seen in the field of rehabilitation engineering, which will be made clear later on. An advantage, and at the same time a disadvantage, is that this approach will come up with non-stereotype jobs. It broadens the possibilities of handicapped people but, because of newness there are no standard procedures and adaptations available.

The production of discrete parts, for example in the metal and electronics industry, is partly automated. Large batches are completely mechanised while very small series and single part production is done manually. In between of these extreme situation there is a growing field for application of industrial robots, called flexible production automation (FPA). This field is growing in the direction of single part production due to decreasing costs of electronics and robotic equipment.

The area between FPA and mechanized production is determined by weighing development costs and investment costs of special systems. The area near single part production is also determinded by the technical possibilities and impossibilities in automated the process when cost limits play an important role. Typical problems are than the costs of sensors and sometimes the unavailability of intelligent software. This is the case, for example, with many quality inspection tasks and when "floppy" material has to be handled. A solution could be in this area of FPA, to use the robot for the "dumb", non-varying manipulation and let the human user solve the (visual) sensor problem and do the intelligent part of the task. We have to be aware that this means that the human worker is included in a repetative production schedule, and in case of a very short cycle-time this will be less attractive although the "human" part in the task always requires typical human functions. It is very attractive in this case that the human part could be done almost equally efficient by a handicapped person as well as a non-handicapped person due to the fact that only the not impaired functional possibilities are used, except computer access.

In the above mentioned situation, the worker has to perform a part of the total product cycle and the robot executes the rest. Other possibilities in FPA for handicapped persons are a supervisory task and a re-programming task. The supervisory tasks requires human senses and intelligence. In addition to this task one could think about giving the supervisor also the possibility to correct errors in certain cases, possibly by means of using the robot itself as a manipulative device.

The programmer's task is of a quite different class. Essential in this job is access to the computer which controls the robot-computer.

For reasons of demonstrative effect and the needs as mentioned in FPA, the first class of jobs, the human disabled operator within the production cycle, is chosen for this project. The first phase of this project is intended to be a study which has to prove and to show the feasibility to production managers and directors of social workshops.

Most robot rehabilitation technology projects deal with the personal use of a robot, or, in that case better to be mentioned as a manipulator, which is an extension of the impaired person (Ref. 1). It will be clear now that this project aims for a complete different use of robot technology.

THE POTENTIAL GROUP OF WORKERS:

It is difficult to define the potential user group because there is no such thing as a group of people with similar impairments which are fitted to this type of jobs. Essentially, the worker in this system can also be a non-handicapped person, because the tasks to be executed require just normal sight, hearing and intelligence. Almost any other function can be impaired without affecting the task performance itself. Thus, normal perception and some form of computer access to control the system is probably the only user group definition from the functional viewpoint. Of course, other criteria has to be met as they are applied to non-handicapped workers.

REQUIREMENTS OF THE COMPUTER ROBOT CONTROL SYSTEM:

The specifications of the feasibility demonstration system is split up in two parts: the general system control concepts and the hardware/software system. The latter will be discussed in the next paragraph.
The specifications of the control system can be derived from the general expectation of the functioning of the system; these are:

- The task which has to be performed.
- A safe operation towards the human controller and the environment.
- Economic and appropriate quality of production.

With a rather simple inspection and/or parts handling task in mind, the following requirements have to be met:

- (Freely) programmable: no implied restrictions on the movements. The programmer should be free to let the manipulator make any sequence of movements within its physical limits.
- Piloting: the possibility of some form of direct continuous control. The user should have the ability to guide the robot directly to positions, controlling it joint by joint or in some combination of joints.
- User interrupts must have the highest priority: always being able to (suddenly) stop the process (an important safety feature!). This will also help in accepting the system since the user is always master over the system.
- Interactive control: pieces of a fixed program fitted into a manually controlled task. The influence of the operator is essential, but complete direct control will slow the system down too much, and does not make use of other advantages of the robot, such as repeatability and accuracy.
- Direct feedback and support of some sensory information: sensors make the use of the system more efficient and sometimes more usable. Not all sensory tasks should necessarily be done by the human operator.
- Easy expandability: e.g. connection to other robot control languages and extra features such as helping the operator when it can be used as a prosthesis.

With this list of requirements it will be clear that the control interface will be very expensive with industrial available robot programming languages. Therefore for this project the choice of control language has been CALVIN which is developed at Tufts Rehabilitation Engineering Center (Ref. 1).

SET UP OF THE SYSTEM:

The computer-robot system is not a real industrial system. The robot itself is not always fast and accurate enough, but can serve very well to demonstrate the principles. The robot is the RTX from UMI-London.
This type of robot is sold to companies which want to simulate large automation projects before selecting an expensive industrial system. The robot is controlled by a MS-DOS based computer system. The control language CALVIN is designed specifically for controlling small robots and has good direct human control features. The language is more a programming environment with the option to execute commands directly or to write a program of commands which can be parsed and executed later on. A "menu" command allows for direct manipulation and defining positions. The Tufts Rehabilitation Engineering Center continues to develop CALVIN to a more reliable control language and with a better definition on the robot interface level. The latter means that transferring CALVIN to another type of robots will be a much better defined job. In addition to the CALVIN software, the TI-Speech System is used for voice control of the system. The TI-system comes with a good menu driven training package and a transparant keyboard facility. This means that, if an application is defined and controlled by the computer keyboard, the change to the voice input system is very easy to do.

REQUIREMENTS FOR A DEMONSTRATION SET-UP IN THE FIELD:

The requirements of a worksite for a try-out experiment should be as follows:

- Cyclic task with reasonable large cycle duration (more than about 1 minute).
- The robot part of the task has to be in itself worthwhile and a feasible automation project.
- There has to be a demand for flexibility; this means a mix of products, changing products and/or a variation in part-feeding.
- Possibly a demand for visual inspection.
- Possibly dirty or hazardous work.
- Provisions for automated transportation of the products has to be available.

This workplace description is not limitative; it gives a typical description of what successful workplace could be.

With respect to the company, the following aspects should be considered:

- The company should already been involved in automation. This new set-up will have its own problems and they should not be mixed with problems of introducing automation.
- The accessability of the workplace for wheelchair-users is a requirement.
- The company and the workers must have a

positive attitude towards employment of handicapped people. This will mostly be sure in case of a colleague who became impaired in this company.
- Flexibility of work organization; it might be a problem that the handicapped person has a limited endurance or requires special attention and organization.

The above described wishes and requirements do not contain difficult problems which are not solvable. But it is already clear in this phase of the project that most of the attention should be given to:
- The social context and implications: The willingness to make a success of this try-out has to be present within the company and with the handicapped person itself. Furthermore, there are a few financial problems to be solved.
- The man-machine interface: A universal interface does not exist. But there are numerous solutions developed for adapting small computers.
- The suitability of the new created workplace for a non-handicapped worker. This is important in case of holidays, sickness and other reasons for absence and it will also diminish the employer's risk (and thus raise the acceptability of this solution) in view of an unsatisfactory situation.

PRESENT STATE OF THE PROJECT AND DISCUSSION:

At the moment a simulation of a workplace in factory reed relais is been build. The factory only produces reed relais and for high quality switching operation a delicate process of cold forming of the contacts, cleaning, plating, finishing has to be carefully verified.
At certain stages of the process arrays of contacts (combs) have to be measured and visually inspected. The probe measurements has to be interpreted and are automatically recorded for statistical processing. A part of this task could be done automatically and a part cannot be automated: Thus an ideal place to demonstrate the possibilities. Real life implementation cannot be done yet because of the fact that the RTX is not having the required industrial specifications.

The project is expected to get a full field trial at the end of this year. There is a strong interest from different organizations because of a recent law in The Netherlands which states that a company should employ at least 5 percent disabled persons. The organizations of the handicapped look forward to get more chances for reasonable work. The social security system which pays an allowance for living is involved very much not for only the financial effects, but helps also companies and people with adapting workplaces. The companies itself will have to face the problems of designing adapted work. A severe problem is how to determine a percentage of "unfitness to work" which is the basis for additional allowance to the prorated salary and is also the basis for counting the percentage of disabled persons in a company. The above described situation of the robot workplace could end up with having severely impaired persons who are not handicapped from the viewpoint of task performance.
A larger national project which studies the influence of automation in the field of work for the handicapped will go along with this project. This project will discover possible workplaces for this applicational study.
Finally, further development of CALVIN is needed. This language offers a lot of possibilities: more than other robot control languages. Interfacing with an industrial robot will require some adaptation of the robot specific software part. Also interactive functions/piloting of the wrist/gripper have to be improved and extended.

ACKNOWLEDGEMENT:

The project is a cooperation between the Department of Flexible Automation of the Delft University of Technology (Prof. L.N. Reijers), Tufts Rehabilitation Engineering Center (Dr. R.A. Foulds) and the Institute for Rehabilitation Research. The project was funded by the Innovation Development Program on Aids for the Handicapped (Director: Dr. J.J. Alexander). The first ideas to start this project came also from this program.

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Special Interest Group 14

Biomechanics

Chair: Peter S. Walker, Ph.D.

HIP DYNAMICS IN STAIR CLIMBING AND RISING FROM A CHAIR FOLLOWING HIP ARTHROPLASTY

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ABSTRACT:

Hip dynamics in three patients with a total hip replacement and one patient with a pressure-instrumented hip endoprosthesis were studied during stair climbing and rising from a chair. Three normal subjects were used for comparison. All hip arthroplasty patients climbed stairs and rose from a chair normally as demonstrated by their hip range of motion and flexion/extension moments. For the patient with the pressure-instrumented hip prosthesis, the peak hip contact pressure for rising from a chair (18 MPa) was nearly twice that measured while climbing stairs although the hip flexion torques were about equal for both activities. This probably represents a greater requirement for muscular co-contraction when rising from a chair.

INTRODUCTION:

Rising from a chair and climbing stairs are two of our most common daily activities. It is obvious when observing a person with severe arthritis of the hip that without good hip function that these two activities can be formidable tasks. This fact is equally clear when attempting to rehabilitate a patient following major hip surgery. Therefore it is important to understand the dynamics of the hip during stair climbing and rising from a chair, and this study will analyze hip range of motion, flexion/extension moments and in vivo contact pressure in patients following hip arthroplasty. Control subjects were used to determine after surgery if hip dynamics approached normal.

BACKGROUND:

Several authors have reported on hip function while climbing stairs or rising from a chair. Andriacchi et al. (1) showed high hip flexion moments occurred in ascending and descending stairs for normal subjects. Andriacchi (2) has also shown that following total knee replacement patterns of bending moments do not normalize. Burdett et al. (3) found high hip flexion/extension moments in rising from a chair for normal subjects and were substantially abnormal in a patient following total hip replacement. Johnston and Smidt (4) have shown that normal subjects require hip flexion of over 100 degrees to rise from a chair and over 65 degrees to climb stairs.

METHODS:

Three patients with total hip replacement and one patient with a pressure instrumented endoprosthesis (5) were studied at least a year after surgery. The instrumented femoral head prosthesis that telemeters interarticular pressure at ten discrete locations 253 times per second was implanted in apposition to natural acetabular cartilage. Three age-matched normal subjects were studied for controls. Simultaneous bilateral kinematic data were acquired with a motion analysis system using a hardware/software system employing four optoelectric Selspot II cameras (Selective Electronics, Partille, Sweden) and an extensive computer program with the acronym TRACK (Massachusetts Institute of Technology, Cambridge, MA) operating on a minicomputer (PDP 11/60, Digital Equipment). Photosterogrammetric reconstruction of serially illuminated infrared LEDs and the aggregation of individual LED three dimensional position data from multiple LEDs on rigid arrays mounted on the body segments permit precise calculation of body-segment 6 degrees of freedom, positions within 1 mm. in a 2-meter cube viewing volume, and orientations within 20 milliradians. The integration of kinematic data with concurrent foot-floor force vector data from two multicomponent force-measuring platforms (Type 9281A, Kistler Instrumente, Wintorthur, Switzerland) permits calculation of bending moments about the hip, using the TRACK/NEWTON software (6). For stair climbing a modular staircase with 18 cm. steps was utilized. For rising from a chair an adjustable, armless, backless chair was used with seat heights at 38, 46 and 53 centimeters. All subjects were studied ascending and descending stairs with each leg. Rising from the chair was performed with the feet parallel but otherwise positioned as the subject preferred.

RESULTS:

When rising from a chair or ascending and descending stairs, subjects with hip arthroplasties had hip range of motion and hip flexion/extension moments within the normal range. Since both the patient group and normal group had similar findings for each test the combined mean test value for all subjects is reported below. For rising from a low chair (38 cm.) the mean hip flexion required was 99 degrees: When rising from a medium (46 cm.) and high (53 cm.) chair, 88 degrees and 80 degrees respectfully were the mean hip flexions needed. The mean hip flexion/extension moments (normalized to height and weight to give dimensionless units) for the various chair heights were 75 units from the low chair, 72 units from the medium chair and 67 units for the high chair. On stairs, subjects needed an average of 63 degrees for ascending and 25 degrees for descending. The mean hip flexion/extension moments were 70 units for ascending and 50 units for descending. When analyzing right and left side variations in hip flexion/extension moments, it was noted that each subject had a dominant side which for the patients was their non-operated side. In the patient with the pressure-instrumented hip prosthesis the peak hip contact pressure for rising from a chair (46 cm.) was 18.0 MPa (see Figure 1), for ascending stairs was 10.2 MPa and for descending stairs 4.4 MPa.

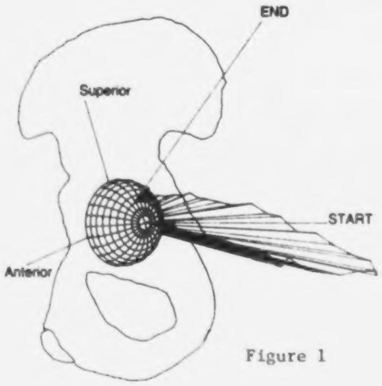

Figure 1

The location on the acetabulum, and the magnitude of pressure of the highest reading transducer in the femoral head as the subject rises from a 46 cm. chair. Each vector shows location and magnitude in equal time steps from start to end. The largest vector is 18 MPa.

CONCLUSIONS:

1) When rising from a chair or climbing and descending stairs, subjects with a hip arthroplasty had normal hip range of motion and flexion/extension moments.

2) The magnitudes of hip flexion/extension moments were similar for both climbing stairs and rising from a chair, but were about 25% lower when descending stairs.

3) Patients with a hip arthroplasty in general had higher flexion/extension moments on their non-operated side while normal subjects were higher on a dominant side.

4) When chair height was lowered from 53 cm. to 46 cm. to 38 cm. the hip range of motion and flexion/extension moments increased.

5) In the patient with the instrumented endoprosthesis, maximum hip contact pressure while rising from a chair (18 MPa) was nearly twice that during stair climbing, although the magnitudes of flexion/extension moments remained nearly equal. This seems to indicate a large requirement for muscle co-contraction during rising from a chair.

DISCUSSION:

Our findings suggest that following hip arthroplasty hip dynamics during rising from a chair and ascending and descending stairs can return to a near normal state. Andriacchi (2) found that following knee arthroplasty, knee dynamics usually did not return to normal. The hip flexion/extension moments are high for these activities and this is in agreement with the findings of others (1 and 3). The hip range of motion requirement during these activities was documented and this also is in agreement with others (4). Asymmetrical loading during tests indicated a dominant leg for each subject which for the patients was the non-operated side. Similar asymmetry was reported by Andersson et al. (7) when looking at knee flexion/extension moments rising from a chair. It was quite interesting to find that despite the fact that hip flexion/extension moments were similar for rising from a chair and ascending stairs, the peak hip contact pressure was nearly twice as great for rising from the chair. This phenomenon during rising from a chair appeared to be due to the increased muscle co-contraction produced about the hip. The incremental, but balanced, agonist-antagonist co-contraction made no contribution to the net hip moment. Preliminary EMG studies are being conducted to investigate this.

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The Added Torque Imposed on the Lumbar Spine During Whole Body Vibration Estimated Using Trunk Muscle Electromyography

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ABSTRACT

We have estimated the average and peak-to-peak torque imposed on the spine during whole body vibration, by measuring the electromyographic (EMG) activity of the paraspinal muscles. Six subjects had surface electrodes placed on their right and left erector spinae muscles at the L3 level. The EMG-torque relationship was estimated by having each subject perform isometric horizontal pulls in an upright seated posture. The subject was then vibrated vertically and sinusoidally in the seated posture, in one hertz increments from 3 to 10 hertz at a 0.1 g RMS seat acceleration level. The subject was constrained to a constant slightly lordotic posture of about 10-15° of forward flexion. Between vibration readings taken at each frequency, a static reading was also taken. The entire vibration-static 3-10 Hz test was repeated for reliability purposes. There was significantly more average and peak-to-peak estimated torque at almost all frequencies for vibration versus static sitting.

INTRODUCTION

Epidemiologic studies (e.g. Frymoyer et al., 1983) indicate significant asociation of the low back complaint with exposures to both industrial and non-industrial vibration. However, relatively few studies have considered the oscillatory load imposed on the spine due to whole body vibration as a possible cause of spine disorders.

Sandover (1981) hypothesized that degenerative changes to the vibration-exposed spine could be a fatigue phenomenon analogous to the fatigue of engineering structures subjected to oscillatory loads. In a study related to the work of Sandover (1981) and Seidel et al. (1986), we have set out to do two things. First, we test statistically whether there is a significant change in erector spinae processed EMG activity in a vibration versus static environment. Second, by converting processed EMG data to an estimated torque about the spine (via an isometric EMG-torque calibration), we attempt to quantify the average and peak-to-peak torque imposed on the spine due to whole body vibration from 3-10 Hz at 0.1 g RMS acceleration.

The subjects first performed a set of isometric pulls against a horizontal cable to establish a calibration of EMG activity versus the torque generated about the spine. After this procedure, the subjects were alternately vibrated and kept in a static posture to determine the effect of vibration on muscle activity.

METHODS

Six male subjects, ranging in height from 165 cm to 193 cm, in weight from 59.0 kg to 90.7 kg, and free of low back pain history, were tested. For measurement of EMG, each subject had two pairs of surface electrodes attached to abraded, cleaned skin at the right and left erector spinae muscle groups (whose EMG signals will be called RES and LES respectively). Inter-electrode distance was 4 cm. The electrodes were placed at the L3 level, 3 cm from the midline of the spine.

For the isometric EMG-torque calibration, the subject sat upright and performed a brief isometric maximum pull against a horizontal cable. Using this maximum as a reference, the subject then pulled at 60%, 40% and 20% of his maximum voluntary contraction (MVC). A reading was also taken of the subject in the same posture without pulling against the load (i.e. 0% of MVC). The test was repeated to give a set of 8 data points to be used for a linear regression of torque about the spine versus the sum of right and left EMG activity. The vertical moment arm of the horizontal cable from the spine at the L3 level was estimated (±2 cm precision) to allow conversion of the cable tension to a torque about the spine.

For the vibration versus static environment testing, the subject maintained a controlled, slightly lordotic sitting posture in approximately 10 to 16 degrees of forward flexion. Once each subject's posture was set at the beginning of the testing, the subject voluntarily maintained this posture throughout the testing by using the tactile feedback from a horizontal bar that was adjusted to fit just below the subject's chin, and from a horizontal tube that contacted the subject's lower back, providing feedback to the subject to maintain the chosen level of lordosis.

In the controlled lordotic, flexed posture, each subject was vibrated vertically and sinusoidally at discrete frequencies between 3 and 10 Hz, in increments of one hertz. At each frequency, the vibration level was set to approximately 0.1 g RMS vertical acceleration, as measured by an accelerometer attached to the seat. While the subject was vibrating, raw amplified RES and LES, the seat acceleration, and the seat displacement measured by an LVDT were recorded on an analog tape recorder. The vibration machine was then turned off and static data were collected with the subject maintaining the same posture. Throughout the paper, static data associated with a given vibration frequency should be understood as the data taken immediately after the vibration data.

After a subject was tested at each of the 8 discrete frequencies (called test 1), the entire test procedure was repeated for reliability purposes (called test 2).

All processing of RES, LES, and the LVDT was performed digitally, using zero phase lag processing techniques to preserve the phase relationship between the electromyographic and displacement data. The sequence of digital processing techniques is shown as a block diagram in Fig. 1.

The raw amplified RES and LES, and the LVDT signal were sampled at 500 Hz for 4 seconds (2000 points) into a microcomputerized data acquisition system (AT&T PC 6300 with a Data Translation DT2801 12 bit A/D Board).

To remove possible contamination of the raw signals by low frequency motion artifacts from the mechanical vibration, both RES and LES were passed through a phaseless digital 6 pole Butterworth high pass filter (HPF) with a cut-off frequency of 30 Hz. The filtered signal was then converted to a measure of the time varying muscle force by rectification and smoothing using a moving window average. To reduce cycle-to-cycle variability in the processed EMG signal, successive cycles were then ensemble averaged. We ensemble averaged to two rather than to one cycle to allow a visual check of the repeatability of the data across cycles.

For conversion to torque, the ensemble averaged right and left EMG signals were then summed and converted to torque using the derived slope and intercept from the isometric EMG-torque calibration. The ensemble averaged torque was smoothed again to reduce remaining jaggedness in the ensemble averaged EMG.

To obtain an estimate of the phase relationship between the LVDT peak (maximum seat height) and the peak estimated torque for the vibration cycle, a circular cross correlation between torque and the processed LVDT was computed for one full time period of the vibration frequency. The LVDT signal received window averaging, ensemble averaging, and a second window averaging to maintain maximum similarity with the EMG processing without affecting the desirable content of the raw LVDT signal. A sample processed torque and LVDT signal are shown in Fig. 2.

The average (AVG), maximum (MAX), and minimum (MIN) of the two-cycle ensemble averaged torque (Nm) and LVDT (mm) signals were computed automatically in the data reduction program.

RESULTS

The isometric EMG and cable force data were sampled for 3 seconds at 500 Hz. The EMG signals, RES and LES, were put through the same digital high pass filtering, rectified and then averaged to single values over the 3 second interval. A regression of torque (X) versus the sum of RES and LES (Y) was performed for the 8 data pairs (60, 40, 20, 0% MVC x 2 trials) for each subject individually. The coefficients of determination were fairly high, ranging from .858 to .970 suggesting that this is a valid technique, for each individual, for converting paraspinal EMG to estimated sagittal plane torque about the spine at the L3 level.

The actual acceleration at each frequency deviated from the desired level of 0.1 g RMS, due to an instrumentation error in accelerometer measurements. The actual RMS acceleration levels, in units of g, were derived from the LVDT measurements using the following relationship for sinusoidal oscillations:

$$a_{RMS} = Kf^2 X_{pp}$$

where X_{pp} is the peak-to-peak LVDT signal in mm, f is the vibration frequency, and K is a constant equal to .00142 accounting for conversion factors. Actual acceleration levels declined from .162 g RMS at 3 Hz to .056 g RMS at 10 Hz, and averaged .104 g RMS across all frequences. Although the RMS acceleration levels varied across frequencies, they were fairly constant at each frequency, as indicated by low coefficients of variation (3.1% to 13.7%) in the measured peak-to-peak LVDT displacements.

To give a qualitative view of the effect of vibration on muscle activity, Fig. 3 shows the output and the resultant change in the raw EMG signal when the vibration machine was abruptly turned off. It can be seen that the raw EMG changes from providing cyclic bursts of activity synchronous with the mechanical vibration to a more steady output characteristic of isometric muscle contractions.

For the mean of the six subjects, the test 1 and test 2 MIN, MAX and AVG torques generated during a vibration exposure are plotted as a function of frequency in Fig. 4a. Fig. 4b shows the corresponding static data. The close agreement seen between test 1 and test 2 data suggests that, for estimating mean torque magnitudes, the methodology used here is repeatable. The test 1 and test 2 data were therfore pooled.

To answer whether there is a significant change in muscle EMG activity, converted to torque, as a result of whole body vibration, two sets of matched pair t tests between vibration and static data were devised. For each frequency, for the sample of six subjects (degrees of freedom = 5) using pooled data from test 1 and test 2, we examined: 1) the AVG torque, computed for the two-cycle ensemble, and 2) the peak-to-peak torque, taken as the difference of the MAX and MIN torque, computed from the two-cycle ensemble. Theoretically, the static peak-to-peak torque should be zero since there should be no change in torque for the static posture. However, for the mean data, as much as a 20% variation from the AVG torque is observed (see Fig. 4b). The static peak-to-peak data is therefore used in the statistical analysis as a measure of inherent variability in the torque data, existing independent of vibration.

Using $p < .05$ as the threshold of significance, we found significantly higher average torques for the vibration versus static data except at 3, 4 and 10 Hz, which were approaching significance ($p < .10$). Across all frequencies and all subjects, the mean difference between vibration and static average torque was about 2.8 Nm. Significant increases in the peak-to-peak torque generation were found at all frequencies for the vibration versus the static environments.

The phase relationship between the LVDT and torque is defined, in seconds, as the time lag between the peak LVDT signal and the peak torque. The overall mean time lag, for all frequencies, was 81 (±19) milliseconds, based on 36 samples. In computing this mean, we excluded the data from some subjects, at some frequencies, which did not show cyclic muscle activity, defined as two evenly spaced peaks in the ensemble averaged torque.

CONCLUSIONS

1. A methodology for estimating the torque imposed on the spine during whole body vibration has been developed and tested.
2. This methodology is based on surface trunk muscle EMG measurements and signal processing techniques designed to enhance the cyclic muscle activity observed during whole body vibration.
3. Based on our chosen method of processing trunk muscle EMG, significant cyclic variations in torque, as well as significantly higher average torques exist for the vibration versus static environments.

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Fig.1 Signal Processing Technique.

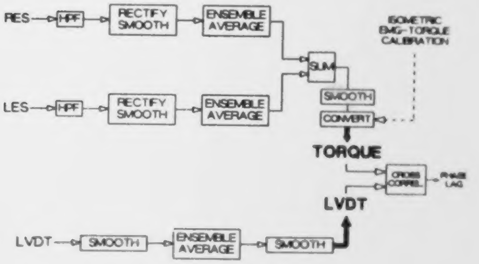
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Fig.2 Estimated Torque & LVDT

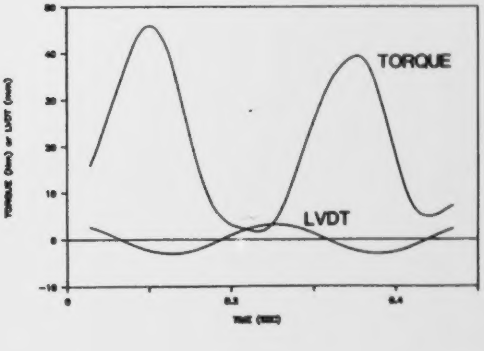


Fig.3 EMG During & After 3 Hz Vibration

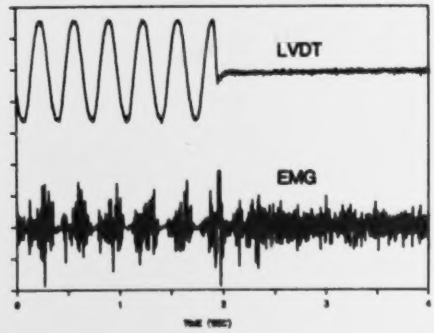


Fig.4a Test 1 vs Test 2: Mean Vibration Data

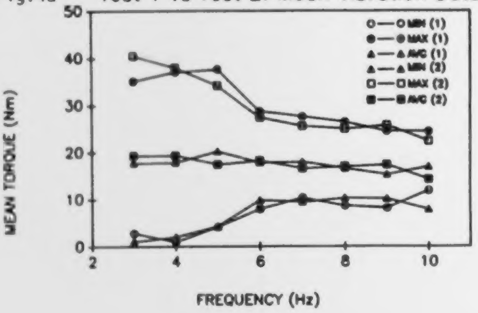
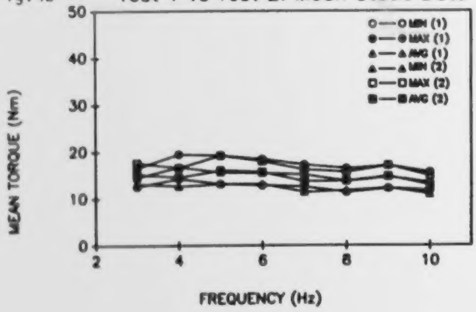


Fig.4b Test 1 vs Test 2: Mean Static Data



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FINITE ELEMENT ANALYSIS AS A METHOD OF PRESSURE PREDICTION AT THE BELOW-KNEE SOCKET INTERFACE

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Prosthetics Research Laboratory

ABSTRACT

This study attempted to predict pressures developed between limbs and prosthetic sockets using finite element analysis and check the results with experimentally measured pressures. After much investigation, a semi-solid/solid pressure measurement methodology was developed which employed miniature strain gage based diaphragm transducers mounted within epoxy collars to provide a flush fit between the transducer and collar faces. The system provided repeatable linear measurements but was dependent upon the semi-solid used. A three-dimensional finite element model (1282 node; 1017 linear solid and 340 spring elements) of a subject's limb was created to represent soft tissue, cartilage, bone, and socket liner. Experimental data concerning limb reaction forces and pressures at the liner at several points was obtained. Pressures measured were matched to results of finite element analyses (based upon measured reaction forces) of the limb/socket system. Pressures measured ranged from 0 to 11 N/cm^2, while predicted pressures ranged from 0 to 9 N/cm^2. Though the range of pressure was similar, prediction of pressures over discrete areas remained nebulous. It is felt, however, that refinements to the model will allow for higher correlations between predicted and measured pressures.

INTRODUCTION

Prosthetic limb replacement following lower limb amputation is intended to restore normal appearance and functional mobility to the amputee. Much of the success or failure of a prosthesis can be attributed to the design of the socket which provides an interface between the natural and artificial limb segments. Key considerations in the geometric shaping of sockets are the distribution of pressure on the interface, suspension of the prosthesis, and limb stability. Pressure at the interface is of principal importance since it has a direct effect on comfort and long term tolerance of the prosthesis. For this reason, the socket shape is not merely a negative replica of the distal limb, but rather is sculptured in an effort to achieve a particular kind of pressure distribution. Modification of socket geometry is one way to control interface pressure. The use of liners at the interface, alteration of foot alignment position, and flexible socket materials also have an influence on socket interface pressure. To our knowledge, quantification of the resultant pressure distributions produced by these procedures does not exist. We feel such quantification is necessary in providing understanding and future advancement to prosthetics.

In an effort to understand BK socket-residual limb mechanics, we developed an experimental pressure measurement methodology and a finite element model of the bone-tissue-socket system in order to predict these pressures. Beginning with simple but realistic assumptions, we assigned mechanical properties to the elements of the model and ran a simulation. The input variables were socket geometry and external force vector which were measured experimentally from a volunteer during stance. The output was the resultant pressure contours at the tissue-socket interface which were compared to pressure measurements made on the volunteer.

BACKGROUND

Efforts to quantify design parameters used in the manufacture of lower limb prosthetics began in earnest in the late sixties to mid-seventies. These generally centered on determining pressures and the factors that influence pressures between the tissue and socket [1-7]. To account for some of the factors encountered in measuring the pressure between limb and socket (i.e. transducer protrusion [1], material effects [6], alignment [3,5]), many investigators have developed their own unique pressure transducers which are based on varied concepts.

Several groups have proposed computer assisted methods for the design and fabrication of sockets for amputees [8-15]. To our knowledge all of the systems currently in development use interactive computer graphics in a process that mimics the standard hand rectification procedure. While these systems are certainly commendable, they provide advancements only in methodology since they do not provide any new understanding of the effect of rectification on socket-limb mechanics. A full realization of the potential of CAD-CAM in prosthesis design, fabrication and fitting will only result from an understanding of socket-limb mechanics (such as provided by finite element analysis) integrated with automated techniques.

Finite element analysis has been widespread in the orthopaedic research community, particularly total joint replacement, for a number of years. In contrast, there have been relatively few studies, 2-D or 3-D, which have included soft tissues surrounding bone. Most notably, Krouskop et al. have begun to analyze AK residual limbs with finite elements [13].

METHODS

Pressure Measurement

Initial testing considered "bag-type" pressure transducers (Sci-medics). In this type of transducer, a flexible bag filled with a fluid and connected to an external pressure measuring device is inserted into the solid/semi-solid interface. While these transducers are reported to work well in seating pressure studies, they were found to have several features which limited their use in our application. The most significant problem was slow response. To obtain accurate, repeatable results, it is necessary to maintain a constant pressure on the bag-type transducers for a substantial period of time. In our application, this would unrealistically require a test subject to hold a steady stance for a lengthy time period.

A pressure gage manufactured by Motorola (model MPX100A) was also evaluated. This inexpensive system proved to be fast and repeatable. Unfortunately, the measuring surface in this device would deflect under load more than the surrounding prosthetic socket wall, thereby underestimating the pressure. Thus a desired characteristic of the transducer is that its compliance needs to be similar to the compliance of the material in which it is located.

A transducer utilizing a new material, called a force sensitive resistor (FSR), was constructed and evaluated. A thin disk element of this material, which varies its resistance with pressure, was sandwiched between two conductors. This gage reacted quickly to applied loads and was as stiff as its backing, but the material did not give repeatable readings, was non-linear, exhibited hysteresis, and was temperature sensitive. Although initial tests did not permit its use, it should be noted that the FSR material, a new technology, is under continuous development and that with further improvement this material may be useful in pressure measuring applications.

A pressure transducer of the diaphragm type was evaluated next. This gage was found to be fast and repeatable in our application and had a compliance more like the socket wall. The original diaphragm PT tested had a 3/4 inch diameter. Tests showed that, because of socket curvature, such a large transducer would not be suitable. Therefore, a smaller transducer of the same type was chosen. The transducer selected was a ruggedized, miniature Kulite pressure transducer (model XTM-190) with a maximum rated pressure of 0.35 MPa and sensitivity of approximately 170 mV/MPa. The transducer weighs 8 grams and has a diameter of 4.0 mm. The sensing element is a piezoresistive strain gage bridge circuit mounted on a metal diaphragm. Its small size and flush mounting capability enabled placement of the device without severely altering the existing geometry of the socket and thus the local pressure.

We could not obtain consistent results when the transducer alone was mounted in the socket because it could not be made exactly flush with the inner surface. To ensure that the transducer's face would be flush with the socket, epoxy collars with a flat face one centimeter in diameter (larger than the diameter of the transducers) were machined to hold the transducers. The flat collar surface formed a small "area of measurement" on which the transducer could be mounted flush to the surface and locked into position (Figure 1). The use of a finger-nail test was found more than adequate in determining the flushness of the two faces. Although the addition of the collar would slightly increase the alteration of the actual socket shape when the collar was threaded into the socket, the forcing of a flush fit of transducer and socket was felt to be of prime importance to ensure proper gage readings. The collars also allowed the transducers (with collars) to be calibrated outside as they are situated *in situ* by threading them into the center of a leveled three-legged platform and applying known pressures in one of two ways. Hydrostatic pressure was applied directly by holding a hose from a gas supply over the face of the collar. Results were read directly from a Bourdon tube low pressure gauge as well as from the output of the transducer. Mechanical pressure was applied by placing a disk (1 cm diameter) of the semi-solid material to be used as the socket liner into a cup which fit over the collar face. Static weights were hung from a lever attached to the platform which transferred the load at a ratio of 5:1 onto a ball bearing placed on the cup containing the semi-solid. Pressures were calculated by dividing the load by the area of the collar face to which it was applied.

Transducers were then mounted into the subject's test socket at seven "ports". In brief, the placement of the transducers was at the distal end, medial tibial condyle, popliteal area, patellar tendon bar, medial proximal tibia flare, distal lateral contact area, and below the fibular head. The socket was donned by the subject and pressure data obtained.

Finite Element Analysis prediction of pressure on the Limb

Three-dimensional geometry of a subject's limb was obtained from multiple transverse CAT scans (1 cm spacing). The CAT scan images were then digitized by hand on a tablet. Of the levels imaged, 13 were chosen for mesh development which represented critical geometric occurrences. The mesh consisted of 1282 nodes defining 1017 linear 3-D isoparametric elements which represented the limb. Approximately 340 linear spring (boundary) elements were added normal to the surface nodes of the mesh to represent the socket liner. The boundary elements act simply as linear springs resisting deformation and thus only require a spring stiffness. For Pelite™, this was obtained by use of an MTS materials testing machine and found to be 145 N/cm. The limb elements were assigned properties of bone, cartilage, or soft tissue as appropriate. Bone and cartilage properties were obtained from the literature.

Young's Modulus (E) for the soft tissue was obtained as follows: A plunger device was designed which consisted of a small load cell and an LVDT and would therefore output load/displacement curves. A socket was created for the subject which possessed seven ports to which the plunger device attached. These ports corresponded to the points at which pressure was measured experimentally. With the subject standing, the plunger was depressed into the tissue and load-displacement curves obtained. The seven ports were identified on the finite element model, corresponding socket liner elements removed, and unit normal compressive loads applied to each. The model was given an initial E value of 85 KPa (a value previously obtained experimentally at this laboratory) and the finite element analysis (FEA) performed. For this linear model, the values of displacement and E are proportional. Thus by comparing the ratios of experimental and predicted FEA displacements at the ports to the value of E used in the analysis, an experimentally obtained average value of Young's modulus was calculated and found to be 60 Kpa.

To the model, the proper loads and moments must be applied to simulate normal stance of the subject. To obtain this information, the subject stood on two force plates (Advanced Mechanical Technology, Inc.) which measured XYZ forces, moments, and center of pressure. The subject was informed of weight distribution by observing oscilloscopes connected to the plates, and told to find and hold a comfortable position at near half body weight. Orientation of the limb was measured simultaneously using a CODA-3 Scanner (Movement Techniques, LTD.). Also measured were pressures at the "port" areas by means detailed earlier. The experimental set-up is pictured in Figure 2. Sampling occurred every 10 seconds for 1 minute. The load and orientation data were transferred to the finite element model by locating CODA marker positions in a 3-D coordinate box and relating their location (using basic coordinate transformation techniques) to reference points on the socket which had been identified on the finite element model. The resulting force and moments obtained for the sampled stance were transformed from the foot to the proximal femur in the finite element model by satisfying equilibrium conditions.

RESULTS

Transducer sensitivity values obtained via the hydrostatic pressure calibration corresponded well with factory calibration values. This indicated that addition of the collar did not affect the performance of the transducer. Calibration of the transducer with a semi-solid also provided linear, repeatable results but produced transducer sensitivity values that were always below the rated sensitivity of the transducer and that were dependent upon the semi-solid chosen. Sensitivity values obtained for Pelite were consistently 30% (± 2%) lower than the transducer's rated sensitivity while values obtained with rubber were 5% lower.

These discrepancies may be attributed to both actual differences in the pressure due to deformation in the elastomer and to transducer induced effects. However, initial testing showed the Kulite miniaturized diaphragm PT system, given careful installation and calibration, to be quite repeatable even between consecutive donning of the prosthesis. It was felt that the pressure measurement system provided sufficient accuracy to proceed.

The finite element code (SAP IV™) was then modified to compute and display element surface pressures from principal stresses (Figure 3). The finite element analysis was performed and resulting predicted pressures ranged from 0 to 9 N/cm^2 (0.6 at the popliteal artery; 9 at the patellar tendon). In initial analyses as of this writing, the pressure profile appeared intuitively correct but has not corresponded completely to the measured pressure profile which similarly ranged from 0 to 11 N/cm^2 (zero at the popliteal artery; 5 at the patellar tendon).

DISCUSSION

This lack of correspondence could be due to several factors. For this initial study, we examined amputees who were wearing comfortable, well fitted sockets. These sockets had been made from rectified molds that may not provide the contact continuity assumed in the model and probably caused tissue deformation even under no load. Also, the mesh may not be fine enough to identify local bony prominences. The soft tissue and/or socket liner may better be represented by a non-linear elements. Finally, calibration of the transducers for the initial tests did not strictly employ the methods already outlined and therefore may not be completely reliable. All of these factors can be accounted for in the model and will be explored in future studies of FEA in the design of prostheses.

During this initial work, it was noted that each analysis of the finite element model possessed a large "turn around" time in the creation, manipulation, and especially the comprehension of the results. A large part of this awkwardness was due to the code (SAP IV™) and our pre- and post- processor (NUFIG3D). It was felt that the capabilities of commercially available codes and processors were far ahead of our capabilities and that if acquired, would reduce the "turn around" time considerably. We are converting existing models to a new non-linear mainframe computer based code (MARC™) and another personal computer (PC) based code (GIFTS™). The PC code runs on an IBM AT, greatly simplifies pre- and post-processing, and actually can analyze the large 1300 plus element model used in this project during an overnight run.

The fact that it is possible to run a large finite element model of the below-knee socket on a personal computer (IBM AT; 30 MB) is very encouraging. Although it takes between 5 and 11 hours to run a simulation, once the geometry and boundary conditions for a particular problem have been defined and saved (i.e. the stiffness matrix formed), a re-analysis of a different load state on the same problem can be done in as little as 45 minutes. This was not possible a few years ago. At the rate personal computer capacity is increasing in speed and memory, it is reasonable to visualize that, within another few years, well conceived complex models could be solved on inexpensive personal computers in reasonably short periods of time (e.g. two hours for analysis, 20 minutes for re-analysis). This is an exciting prospect in view of the potential benefit of finite element methods as a clinical tool for prosthetists.

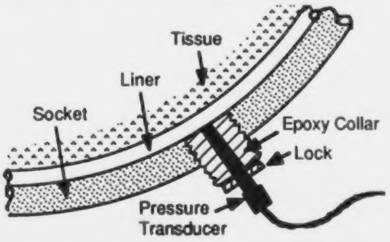

Fig. 1: Schematic of pressure measurement system. This arrangement presents a 1 cm diam. area to the liner.

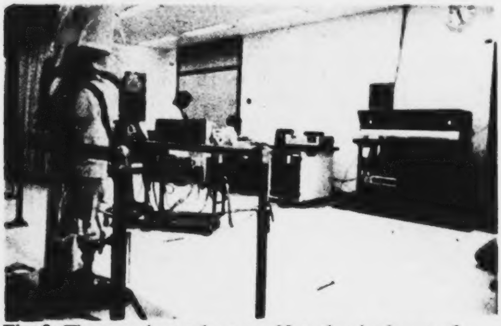

Fig. 2: The experimental set-up. Note the six-degree of freedom force platforms upon which the subject stands and the socket which is instrumented with pressure transducers. On the right of the photo is the CODA-3 measurement system which references the position of the socket to the force platform.

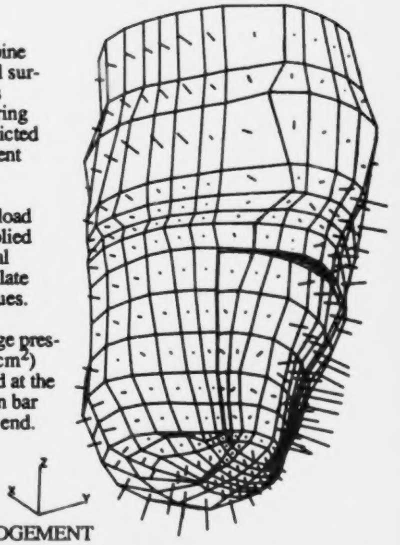

Figure 3:

Vector porcupine plot of normal surface pressures developed during stance as predicted by finite element analysis.

A moment & load have been applied to the proximal femur to simulate measured values.

Relatively large pressures (5-9 N/cm^2) were predicted at the patellar tendon bar and the distal end.

ACKNOWLEDGEMENT

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GENERATION OF SURFACE ANATOMY FROM CT and MRI IMAGES

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ABSTRACT

The emerging sophistication of computer graphics capabilities has produced a comensurate increase in the complexity of the problems that are being approached from a graphical perspective. Computer assisted anatomy display is one such issue that many investigators have been addressing. In this paper we present our approach for the automated generation and display of patient specific anatomy stressing the ability to perform modifications of the anatomy on the computer, motivated by a plan for Computer Assisted Surgery. The surfaces generated are dervived from cross-sectional images of the body acquired via CT and MRI technologies. These images are processed to define the boundaries of anatomical components, which are then used to generate a Fourier Descriptor based representation of the surface of constituent anatomical parts. This representation is then converted into a flexible database comprised of a unidirectional linked list of surface elements which compose the complete surface representation. Our Results indicate that realistic and memory efficient surface displays can be accomplished that permit simulation of simple surgical intervention such as a femoral osteotomy.

Introduction

The advent of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) technologies, both of which convert anatomical information into cross-sectional images, have prompted physicians to become more conversant with cross-sections of human anatomy. This need coupled with advances in engineering technology in image analysis and interpretation has resulted in the increase in design and implementation of algorithms which can aid the physician[1]. In particular there has been great emphasis in assisting the physician to synthesize three dimensional relationships from these cross-sectional images[2].

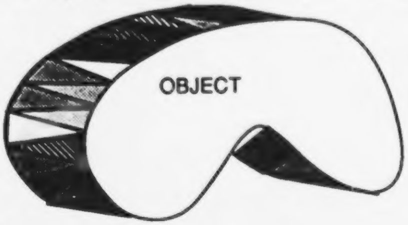
Current approaches have pursued the display of three dimensional surfaces constructed from contours extracted from sequential images[2] . Though results are promising they often require manual intervention during surface construction[3]. Many of these approaches result in discontinuous surface representations due to the discrete nature of the images from which contours of varying numbers of points are extracted[4]. Since these surface representations are not easily amenable to integration in current state-of-the-art computer aided design software products, future mesh generation techniques need to address these shortcommings for future implementation of concepts such as Cumputer Aided Surgery[5].

Methods

Our research has been directed towards the development of techniques to rectify these short commings so that clinicians can manipulate anatomical relationships. CT and MRI images were obtained from the Massachusetts General Hospital, courtesy of Dr. Michael Goitien and Dr. Bruce Rosen. The images were analyzed on a Silicon Graphics IRIS 2400 Workstation (Mountain View, Ca.) operating under the UNIX operating system. In this study a searching algorithm independent of the determination of a threshold tolerance was used for contour following[6].

Fourier descriptors were used to compress the contour data and as a data base representation used in shape classification[7]. This data format was exploited in shape identification, data compression, and surface generation [8]. The two dimensional coding of contours from CT and MRI scans by Fourier Descriptors (FD) allows for contour filtering and for the normalization of all contours to a constant number of points, thus simplifying the task of mesh generation. Once a contour description for each anatomical object is derived a mesh of triangular patches is constructed for display on the computer screen, as in figure 1.

Figure 1. Representation of an object composed of patches



Data Structures

The data format used for object display consists of a unidirectional linked list of triangular surface patches and an associated internal object axis matrix such as shown in figure 2. The internal object axis is used for transforming the position and orientation of each individual object in space. The flexibility using a linked list of patches evidences itself in the ability to circumvent a priori assumptions regarding the size limitations on any single surface mesh. This flexibility is managed by the use of numerous pointers to constituent elements, for example a patch maintains pointes to the coordinates that define it, a surface normal for shaded dirplay, and a pointer to the next patch, thi is shown in figure 3.

Figure 2 Constituent elements of an Anatomical object

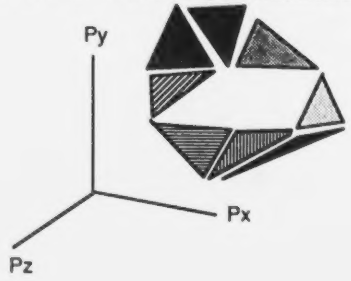
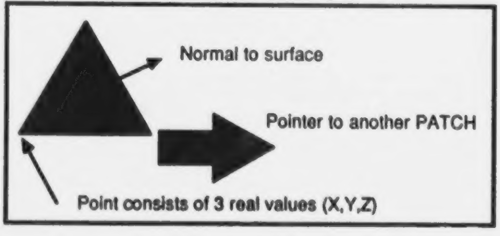


Figure 3 Constituent elements of a PATCH



One primary advantage in utilizing a pointer based representation in the linked list is to eliminate a prior allocation of too much or insufficient memory to represent an anatomical object of arbitrary complexity. If alternatively a fixed degree of complexity is pre-defined, storage is limited to that size by the computer, resulting in situations when the storage allocated is either redundant or insufficient. Thus by use of a pointer based linked list, memory for each patch is allocated dynamically as the linked list grows, resulting in the appropriate allocation of memory for an arbitrary object.

Such a flexible data stucture is perfectly amenable for the display, description and manipulation of a wide range of objects regardless of physical size or of the number of surface elements that comprise its representation. This representation allows for the modification of a given object's geometric description without altering the basic representation used by the computer. It is our thesis that this linked list apporach can be used for many of the functions that would be required in Computer Assisted Surgery.

For example, to perform operations involving two objects such as a cut or glue operation, it would suffice to manipulate their respective surface patch lists. If one has two objects such as in figure 4 then a gluing operation of the two together is merely an appending of the list of patches of one object onto the other such as in Figure 5. Note that the Null_patch is an element used to define the end of a list.

Figure 4.Representation of Two objects by their surface patches

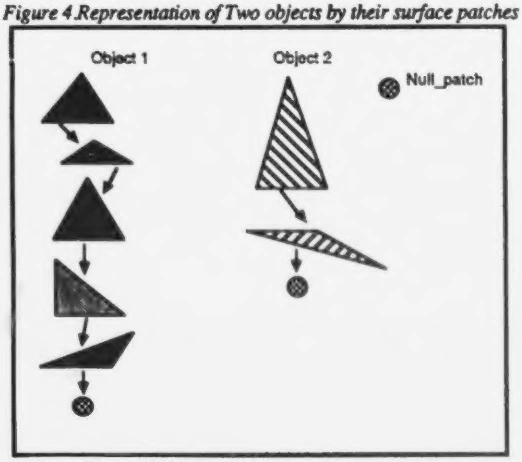
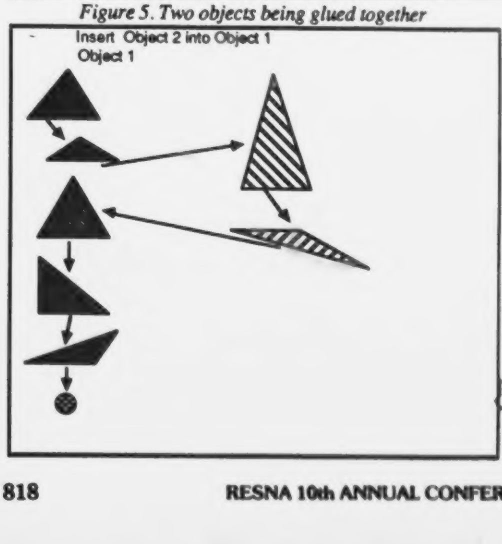
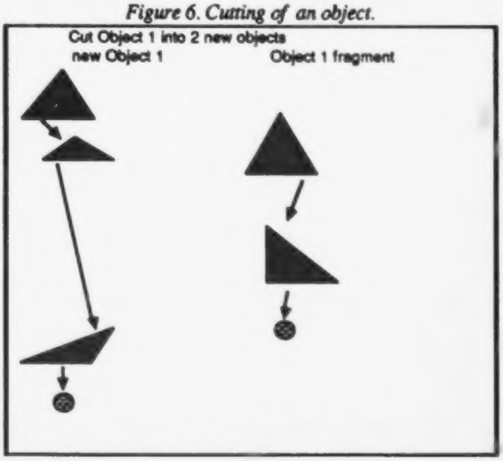


Figure 5. Two objects being glued together



To perform a cutting of a section from a given object would entail the elimination of a subset of patches from the chosen objects list as is shown in Figure 6.

Figure 6. Cutting of an object.



Results

Preliminary studies with regular geometric shapes have demonstrated the efficacy of the linked patch approach for display and geometric manipulation. Results from image contouring an image in the femoral-patellar (FP) region of the human knee can be seen in Figure 7. A Fourier Descriptor based collection of contours of the distal end of the femoral condyles from images surrounding this same region can be seen in Figure 8. A typical mesh generated for this distal end of the femoral surface can be seen in Figure 9. Lastly the complete linked list representation of the distal end of the femur extracted from this data with an end capping applied is shown in Figure 10.

Figure 7. Contours from Image from Femoral-Patellar region.

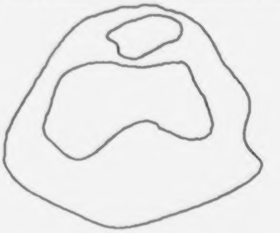


Figure 8. Filtered Contours from images of FP region.

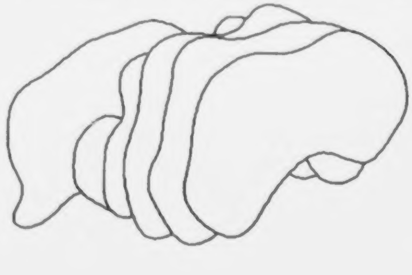


Figure 9. Contour Based Surface Mesh of Distal Femur.

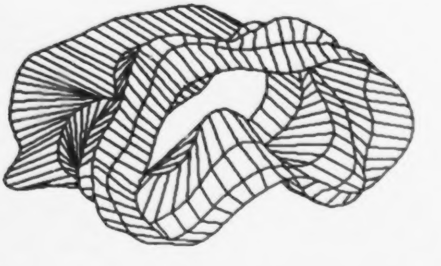
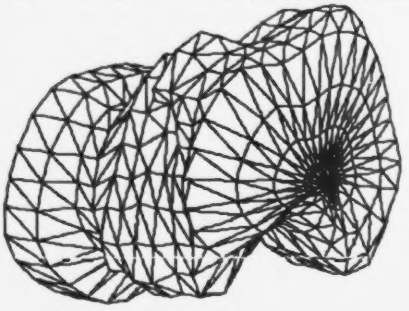


Figure 10. Complete Linked surface of distal Femur.



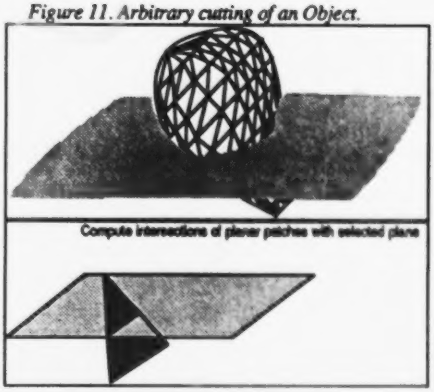
Discussion

Prior results have indicated that automated contour extraction, object recognition, and reconstruction from cross-sectional images of human anatomy can be performed effectively, reliably, and rapidly. However a major impediment to applying these to surgical simulation has been the rigidity of contour based surface displays. Thus the flexibility achieved by a patch-list-based representation offsets the complexity in memory management required by such a scheme. Once the three dimensional anatomical objects are generated the physician can then direct the computer to calculate geometric properties to assist in planning surgery.

The current results with the display of the data representation and its integration with our prior work indicate that visually appealing results can be accomplished. We are encouraged that surgical simulation will be possible with this data representation and we are planning algorithms that will deal with the general problem of cutting an object in such a way that constituent patch elements are fragmented such as would occur if an aribtrary plane were passed through an object and individual patches were cut into a number of smaller patches such as in figure 11.

As many computer-aided design systems have demonstrated remarkable manipulative power and cost effectiveness in engineering environments, it is expected that a surgical simulation system can achieve similar sucess. We are encouraged by the prospect of manipulating a more general class of objects.

Figure 11. Arbitrary cutting of an Object.



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THE EFFECT OF FOOT WEDGING ON KNEE AND ANKLE MECHANICS

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Patients with knee varus deformities have increased loading in the medial compartment of the joint. A study was undertaken to determine if wedging of the shoe would modify the coronal plane moment at the knee by moving the ground reaction laterally. This should decrease the adduction moment so studies of lateral wedging of the foot was undertaken as well as studies of medial wedging for the opposite effect. Eight male volunteer subjects were studied (age 19-65). A computer produced an analysis of center of pressure on the foot and correlated this with the gait analysis. During the first 20% of stance, heel wedging slightly decreased adduction moment at both ankle and knee. In two patients with knee varus, one had symptomatic relief of knee pain using a wedge, the other showed changes similar to normal subjects but with no improvement of symptoms.

Pain in the osteoarthritic knee is dependent on the load across joint surfaces. Patients with varus deformity of the knee have increased loading in the medial compartment due to an increased adduction moment. The study was undertaken to determine whether wedging the foot could modify the coronal plane moment at the knee. The hypothesis was that lateral wedging of the foot by moving ground reaction force laterally would decrease the adduction moment. If this were true, lateral wedging in an ankle foot orthosis could provide symptomatic relief in patients with painful varus deformity.

Eight normal male subjects (age 19-65) wore Adimed boots (special reinforced surgical boots) and walked across a gait analysis pathway over the two Kistler forceplates and in view of four television cameras linked with a DECPD11-23 computer through a Vicon interface. Retroreflective markers stuck to the skin over anatomical landmarks in the lower limbs were used to record gait cycle and changes were monitored as the subject wore the shoes with and without the wedges. Two runs were recorded with the boots alone, two with the lateral 10 mm. wedging, and two without the medial 10 mm. wedging, all on the right foot. In addition to the forceplate and the visual imaging, a transparent overlay traced from the subject's shoe was aligned so the computer could reconstruct the position of the foot in relation to the force platform data as the center of pressure shifted beneath the foot during weight bearing on the platform.

In the preliminary study, one subject wore an ankle foot orthosis and the wedges. This showed that with the AFO, the effects of wedging were far more marked than those in the Adimed surgical boots. However, all normal subjects showed some changnes in adduction moment during the first 20-30% of stance phase; medial wedging increased the adduction(varus producing momemt) both at ankle and knee; lateral wedging reduced it. However, the changes were rather small endmostly during the gait phase prior to mid-stance.

Two patients were studied, one reported symptomatic relief of his knee pain although he showed little change in the knee and ankle moment. The other showed changes in moments similar to those seen in normal subjects but without any improvement in symptoms. Notably, the first patient had marked mediolateral knee instability; the second, a rather rigid knee. The lines of center of pressure on the outline of the foot of the eight subjects showed a small change in the expected direction but only as long as the heel was in contact with the floor. This was lost or even reversed after the foot flat phase of stance.

Two hypotheses were considered to explain the relatively small changes observed in the ankle and knee moment; either the feet were placed on the ground more laterally or more medially to minimize effects of wedge, or the wedges were beneath the foot, The first hypothesis was tested by examining the width of walking base. Although this varied considerably from one walk to another with the same subject, there was no consistent pattern to suggest an increase in width of walking base with a lateral wedge or decrease with a medial wedge. As noted in the results, the center of pressure through the foot showed only a small change and only when the heel was in contact with the floor.

The results from the patients added little information as the change in symptoms did not appear to relate to the biomechanical measurements. However, as only two subjects were tested, this should be studied further before reaching definite conclusions concerning effects of foot wedging.

For some osteoarthritic patients, lateral shoe wedging combined with subtalar immobilization may be useful in altering knee and ankle moments and thus help alleviate symptoms. Only minor alterations were seen in the present study of normal subjects and this may be due to inadequate mobilization or the wedging being too thin or too compliant. In a preliminary study on patients, the rather marked knee instability of a patient who experienced relief perhaps suggests that wedging may be more helpful in such cases than in those with rigid knees.

THE IMPORTANCE OF PHYSICAL ACTIVITY TO THE MAINTENANCE OF BONE DENSITY

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ABSTRACT

Using a mathematical model which relates bone density to daily stress histories, the influence of physical activities on the apparent density of the calcaneus cancellous bone was investigated. Bone apparent density was calculated by a linear superposition of the mechanical stimulus provide by different daily physical activities. An empirical weighting factor, *m*, accounted for possible differences in the relative importance of load magnitude and the number of cycles in each activity. By considering hypothetical variations in body weight and occupational activity levels, the range of probable *m* values was established. The model was then applied to predict the results of two previous running studies in which calcaneal density was measured. The results indicate that stress magnitudes (or joint forces) have a greater influence on bone mass than the number of loading cycles and that the maximum attainable cancellous bone density at a specific site is limited by the maximum achievable muscle force and loading frequency. It may be possible to design execise programs to achieve predictable changes in bone mass by carefully considering the magnitudes of imposed skeletal forces and the number of loading cycles.

INTRODUCTION

Body weight and physical activity have been shown to influence bone density. Large, heavy individuals who are physically active tend to have denser and stronger bones than frail, sedentary individuals. During the course of a day, each leg may experience between 5,000 and 50,000 cycles, loaded by ground reaction forces ranging from less than .5 to more than 3 body weight (BW). While a broad range of physical activity exists among individuals, the majority have established patterns of daily activity which vary little from day to day, and the precise daily loading history may be replaced by an 'average' daily loading history which incorporates a summary of joint reaction forces and number of loading cycles for various activities. With the selection of a range of 'average' daily activity levels, a bone maintenance theory has been implemented to estimate calcaneal density as function of activity level with and without exercise for a wide range of individuals. The calculated values correlate well with results from clinical experiments and observations. These results indicate that a technique which involves careful quantification of physical activity can be used to design exercise programs to maintain or increase bone mass.

BACKGROUND

Previous investigators who have tried to explain the trabecular orientation and bone apparent density within a bone have considered a single 'typical' loading condition to which the body is exposed on a repetitive basis. Most have assumed that bone apparent density distributions within a bone are optimized with respect to some measure of the local ultimate strength, i.e. the ratio of stress to ultimate strength is the same throughout the entire region of bone.

Studies which consider a single load application have proved to be very useful. However, a better understanding of these relationships requires a more complete consideration of the nature of intermittent, repeated loading of bone during daily activities. The model assumes that some relatively stable (homeostatic) situation exists between bone stress and local bone density. The daily activity levels of the individual have been consistent for long enough that the skeleton is not experiencing significant bone loss or gain. The goal is then to determine the relationship between the stress history and the current trabecular bone apparent density at a specific site.

METHODS

A bone maintenance model has been proposed which extracts the number of cycles and peak cyclic stress magnitudes from the 'average' daily stress history to predict bone apparent density, ρ. A bone maintenance stimulus, S, has been defined as the linear summation of the the contributions from all daily loading cycles

$$S \propto \sum_{j=1}^{k} n_j (\bar{\sigma}_j / \bar{\sigma}_{ult})^m$$

In this expression the daily stress history has been grouped into k activities, each of which produces a unique loading state on the body, e.g. walking or running at a steady velocity. The variable, n_j, represents the number of daily loading cycles for the jth activity, and $\bar{\sigma}_j$, a scalar, the peak cyclic effective stress which is calculated from the cyclic stress state. The parameter, m, to be estimated from experiments, determines the relative importance between the number of loading cycles and cyclic stress magnitudes.

Assuming a constant bone maintenance stimulus, S, for all bone tissue, and relating the ultimate strength, $\bar{\sigma}_{ult}$, to the square of the density [1], bone apparent density, ρ, becomes

$$\rho \propto \left[\sum_{j=1}^{k} n_j \bar{\sigma}_j^m \right]^{\frac{1}{2m}}$$

Relative bone apparent density between two activity levels is obtained by equating the two daily stress histories

$$\frac{\rho_2}{\rho_1} = \left[\frac{\sum_{j=1}^{k_2} n_{2_j} (\bar{\sigma}_{2_j})^m}{\sum_{i=1}^{k_1} n_{1_i} (\bar{\sigma}_{1_i})^m} \right]^{\frac{1}{2m}}$$

All significant forces which load the calcaneus can be related directly to the ground reaction force. The peak ankle joint reaction force, and therefore the period of peak calcaneal stress for nearly all activities, occurs during late stance phase when the center of pressure is on the ball of the foot. At this instant the horizontal components of the ground reaction force are not significant compared to the magnitude of the vertical component. Relating maximum cyclic calcaneal stresses directly to the vertical component, G_z, of the ground reaction force during late stance phase, the model simplifies to

$$\frac{\rho_2}{\rho_1} = \left[\frac{\sum_{j=1}^{k_2} n_{2_j} (Gz_{2_j})^m}{\sum_{i=1}^{k_1} n_{1_i} (Gz_{1_i})^m} \right]^{\frac{1}{2m}}$$

where n represents the number of daily cycles at a force level Gz for the each activity. **Peak vertical ground reaction force and cadence data for walking and running, obtained from the literature [2,3,4,5,6], were expressed as functions of gait velocity** in order to calculate average daily loading histories for the calcaneus. The model was applied to data from running studies [7,8] to obtain an estimate of m.

RESULTS

Best fit estimates of the model with previous experiments result in m values between 2.7 and 4.5. Using an intermediate value of m equal to 4.0, calcaneal densities, shown in **Figure 1**, were calculated for the range of activity levels listed in **Table I**. Predicted calcaneal bone apparent density ranged from 77 per cent of normal for the sedentary individual to 117 per cent of normal for the athlete.

The results indicate that jogging exercise is of greater benefit to the inactive person, raising calcaneal density to within 8 per cent of normal. The same exercise program applied to the active person produces little change in bone density. The dominance of the load magnitude is evident from a comparison of the bone density for the athlete with a normal lifestyle and the active person who exercises. Higher ground reaction forces for distance running compared to jogging more than compensate for the 4 hours per day less activity.

The model was also applied to the NASA **Skylab** [9] data and studies which combined bed rest with supplemental exercise. A manually operated treadmill which used stretch cords to simulate a gravity force of 1.2 g's was carried aboard the **Skylab-4** mission. An average of 12 minutes of exercise per day did not alleviate bone loss. Our model, applied to the treadmill program, is in agreement with their data.

Izzekutz [10], in a bed rest study, found 3 hours standing per day to be more beneficial to bone maintenance than cycling at 100 watts output for 4 hours per day. We estimated calcaneal loading histories for each activity. Our estimated values for calcaneal density also concur with their experimental observations. In another study [11], it was reported that walking for 4 hours per day was necessary to maintain a bone density. This is equivalent to our definition of a sedentary lifestyle.

CONCLUSIONS

This work suggests that the stimulus for bone maintenance is at least approximated by a discretized daily loading history which retains the number of loading cycles and maximum cycle effective stresses for each daily activity. The value of the stress exponent, m (2.7 to 4.5), implies that bone density is more strongly affected by increasing the joint reaction forces than the number of loading cycles. Further applications of this method will allow one to predict the benefits of various exercise programs on maintaining or increasing bone density throughout the skeletal system.

ACKNOWLEDGEMENT

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Table I: The list of occupational activities was selected to provide a broad range of loading to the calcaneus. Each activity (i.e. walking, running, etc.) was equated to a gait velocity. Regression equations for cadence and peak vertical ground reaction force were used to compute 'average' daily calcaneal loading histories.

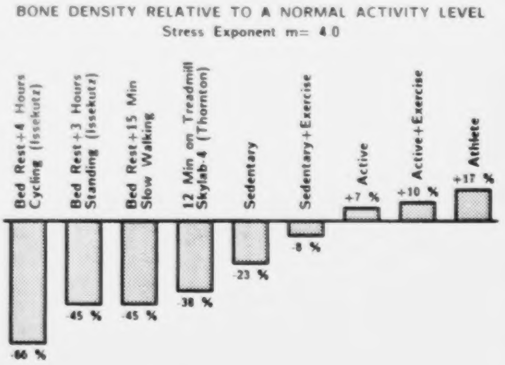
HYPOTHETICAL ACTIVITY LEVELS

OCCUPATIONAL ACTIVITY LEVEL	HOURS SPENT PER DAY			
	Slow Walking	Normal Walking	Fast Walking	Exercising
Sedentary	4	----	----	----
Sedentary + Exercise	4	----	----	.67[1]
Normal	----	4	4	----
Active	----	4	8	----
Active + Exercise	----	4	8	.67[1]
Athlete	----	4	4	.75[2]

[1] 6 Km at a 2.5 m/s jogging pace.

[2] 12 Km at a 4.5 m/s running pace.

Figure 1: Relative calcaneal bone apparent density computed for the hypothetical activities listed in **Table I**. A stress exponent value of $m = 4.0$ was used. Data from bed rest studies and **Skylab-4** are also presented.



INVESTIGATION OF IN VIVO LOADING RATE CHARACTERISTICS IN A HUMAN HIP JOINT

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ABSTRACT

Implantation of an instrumented femoral head prosthesis in June 1984 has produced telemetered output of 10 pressure measurements at discrete locations on the femoral head. This data, and simultaneous kinematic and forceplate data has revealed the presence of high rates of loading, illuminating the dynamic effects of muscle action on the hip joint. The rate of change of pressures at the joint interface has been investigated over the entire course of rehabilitation. Pressure changes at the joint have been compared to external force variations. Certain movements typically produced high loading rates. Timing of pressure rises relative to external forces indicates that muscle forces are important in production of joint loads. High loading rates precede or occur simultaneously with external force application.

INTRODUCTION

Insight into pathological failure of natural joints, improvements in conservative joint surgery, and design of superior joint replacements require knowledge of the loading environment at the particular joint. The hip joint has received major attention due to its relatively simple geometry, importance in weight-bearing activities, and frequent replacement. Gait analysis studies have attempted to quantify the joint reaction forces. All such investigations suffer from the flaw that muscle forces above those producing motion are unknown. Thus, an upper bound on the joint reaction forces cannot be obtained.

The distribution of load on the joint is also of interest, particularly for understanding the mechanisms of cartilage lubrication and the focal nature of osteoarthritic degeneration. To study these issues an instrumented femoral head prosthesis developed at M.I.T. was implanted in vivo in June 1984 [1]. Data from this device has confirmed trends observed in vitro, such as non-axisymmetric pressure distribution and the presence of high pressure gradients [2]. Exploration of the changes in temporal loading that occur during normal in vivo motions became possible. High rates of loading have been observed, primarily during certain movements. No prior data existed on the rate of load transfer and the magnitude of pressure changes and few estimates were available [3]. Quantification of the rate of loading at the hip and its relationship to external forces was documented. Rate of pressure change on acetabular cartilage corresponding to femoral locations has varied with post-operative interval, with movement, and is related to measured external force changes.

METHODS

The instrumented endoprosthesis is designed to function as a Moore-type femoral head replacement [4]. Pressure from the opposing natural acetabular cartilage is measured at 10 locations on the femoral head where the wall thickness has been decreased by machining wells on the inner surface of the femoral ball. Deflection of each diapragm is transmitted to a strain-gaged cantilever beam; the electronic circuitry of each transducer is powered and sampled sequentially. The Pulse Amplitude Modulated (PAM) output is communicated to an external receiver through Frequency Modulated (FM) radiotelemetry. During data collection power is electromagnetically coupled from a garter worn by the subject to an antenna encased in Teflon in the stem of the prosthesis. At all other times the system is not in operation.

Each transducer is sampled at 254 Hz with a series of samples from each transducer called a frame. Since only 3 msec. passes between the sampling of the first and last transducers in a frame and the frequency content of the pressure signals is concentrated below 10 Hz the sampling process is acceptable. During the initial postoperative period (2 weeks) a sampling rate of 10 Hz was used and was too slow for reliable reconstruction of the time-varying pressure signal.

Kinematic and forceplate data are acquired synchronously with the pressure data using Selspot optoelectronic cameras, Kistler forceplates and the TRACK data acquisition system [5]. The kinematic and kinetic data were collected at 153 Hz after 6 months postoperative; prior to that time this data was collected at faster rates. The kinematic data is used to relate transducer locations on the femoral head to positions on the natural acetabular cartilage. Pressure data has been reported elsewhere [1], this paper focusses on the pressure rates.

The simplest method of determining the load rate at a transducer is to calculate the slope of its pressure measurements over the time interval of interest. Limitations with this method include: the time frame must be selected, the transducers must be examined individually, and the acetabular location of a transducer moves over the time interval. Numerical differentiation of the pressure magnitudes over an entire test was considered, however, this requires very smooth data and becomes unstable around abrupt changes. The pressure data contains abrupt changes and reversals during some motions, and these prove to be of especial interest.

Filtered data is used in calculations of rate of loading reported here. Rates of pressure increase are presented in M-Pa/sec. When the rate of change of external forces is given the units are N/sec.

RESULTS

Three classes of results will be presented: examples of fast pressure increases; changes in maximum load rate for a particular movement over time; and comparison of pressure increases to the rate of change of external forces recorded at the forceplate.

The highest rates of change of local pressures were measured when the subject rose from a chair, the maximum being 107 M-Pa/sec at 14 months postoperative. Table I gives maximum load rates for rising from a chair, walking, jogging, and climbing stairs. The estimated movement in acetabular location of the specified transducer as this load rate was experienced is also given. Different motions produced maximum rates on different transducers. Therefore the region of the acetabulum in which high rates of loading developed also depended on the type of movement performed. During separate trials of the same motion the same transducer usually exhibited the fastest change in pressure.

During walking the fastest increases in pressure occurred in the upper posterior region of the acetabulum. The changes in load rate were small over the period from 6 months to 14 months postoperative, ranging from 25 to 40 M-Pa/sec; consistent with the observation that the subject was walking normally 6 months after the implantation.

Results for climbing stairs were comparable to those from level walking, with more regions of the femoral head experiencing an abrupt increase in pressure.

In jogging the maximum changes in local pressure were not much higher than those observed in level walking but more transducers exhibited rapid changes and high pressure values. The change in external force was much greater for jogging than walking.

Most impressive are the high changes in local pressure which occurred as the subject rose from a chair. Initially comparable at 6 months to results found in level walking, these rates of loading continued to increase with time through 14 months after the operation. The highest values were measured in the lower posterior region of the acetabulum. The changes in external force were not high at the time that local pressures registered the greatest increase. In fact, during some tests the force applied to the forceplate was decreasing as the joint pressure rose.

DISCUSSION

The rates at which pressure increased in some regions of the hip joint during rising from a chair were much greater than those observed in other tests. Following in decreasing magnitude of pressure rate were climbing stairs, jogging, and walking. The overall maximum pressure was also recorded while the subject rose from a chair. These results indicate that the transition from sitting to standing position requires substantial muscle involvement, producing high joint loads.

When the subject rose from a chair or climbed stairs the highest pressure changes and the maximum pressures were measured in the smane region of the acetabulum. In level walking the highest rates of pressure increase occurred more posterior in the socket than did the maximum pressures. The highest rates of change of pressure took place in the initial period of foot-floor contact, at which time the hip flexion angle is still decreasing. Maximum pressure increases began before heel strike and preceded the largest changes in forceplate force.

In many movement patterns maximum pressures preceded or occurred simultaneously with maximum forceplate forces as did the maximum changes in local pressures at the hip relative to changes in forceplate force. The relative timing of pressures and external forces appears to be due to muscular contraction in anticipation of external force changes. In some cases the greatest muscular forces are required prior to the application of large foot-floor interaction forces, particularly evident when rising from a chair where the subject begins by rotating her trunk forward about her hip joint.

CONCLUSIONS

In vivo data collected with an instrumented endoprosthesis has shown that high rates of loading are found in the human hip joint during normal movements. Muscle forces, including co-contraction forces, are significant in production of joint loads. There was no previous data on which to base estimates of in vivo load rate, and data exists now for only a single subject. Much information is still to be obtained and these results applied to the studies of joint lubrication mechanisms and joint reconstruction and replacement.

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Table 1

Movement	Pressure Rate [M-Pa/sec]	Arc [deg]	Ext. Force [N/sec]
Level Walking			
6 mo.	30.2 (2)*	7.9	
11 mo.	35.9 (2)	1.5	
14 mo.	33.5 (2)	1.2	
Jogging			
12 mo.	39.2 (2)		3063
12 mo.	44.6 (2)		15193
Climbing Stairs			
6 mo.	44.7 (3)	5.4	2800
	78.5 (5)	6.5	474
11 mo.	59.1 (2)	4.3	223
	58.9 (3)	5.0	501
11 mo.	49.9 (2)	4.7	568
	67.0 (5)	9.4	415
14 mo.	29.7 (2)	2.5	2377
Rising from a Chair			
6 mo.	38.0 (1)	8.3	994
	14.7 (5)	8.6	-36
11 mo.	47.2 (1)	7.2	1553
	38.9 (5)	8.6	-487
11 mo.	85.3 (1)		876
	85.4 (5)		782
14 mo.	107.4 (1)	6.1	41
14 mo.	79.8 (1)	5.0	-547

(*) Transducer number

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METHODS TO REDUCE STRESS SHIELDING IN PLATED BONES

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ABSTRACT

Using a three-dimensional finite element model, we studied load transfer from bone to plate along the diaphysis of a plated long-bone. We examined a standard forearm plate having full-length screws, a standard plate having a shortened outer screw and a tapered plate having full-length screws. The use of either shortened outer screws or a tapered plate resulted in a more gradual transfer of load from bone to plate than that provided by the standard plate having full-length screws. However, the use of shortened outer screws had the potential disadvantage of providing less initial stability for a newly fractured bone. A tapered plate relies on a reduction in plate stiffness near the ends of the plate to provide for a more gradual load transfer. This is done without compromising initial stability.

INTRODUCTION

In recent years much attention has been focused on the problem of bone refracture after the removal of internal fixation plates. Refracture rates between 10% and 20% are not uncommon (1,2). This high refracture rate has prompted some clinicians to recommend against routine implant removal although it is recognized that this is not done without associated risks.

Researchers and clinicians agree that the use of internal fixation plates alters the biological and biomechanical environment of a fracture more profoundly than conservative treatment modes. One concept that has been implicated as a contributory cause of cortical bone osteopenia or thinning which may result in refracture is termed mechanical stress shielding. Mechanical stress shielding refers to the fact that during physiologic loading of a plated long-bone, a portion of the load is transferred from the bone to the plate, thus shielding the bone from its normal level of stress.

Mathematical studies of plated long-bones have shown that most of the load transfer occurs through the outer-most screws (3,4); resulting in an increase in stress near the ends of the plate concomitant with a decrease in stress near the mid-plate cross section. This state of stress correlates well with observations from *in vivo* studies which show bone hypertrophy near the plate ends and cortical thinning and osteopenia near the mid-plate (5,6).

In an attempt to provide a more gradual transfer of load from bone to plate, it has been suggested that the outer-most screw should be shorter so as to engage only one cortex (7). An alternative approach to make the load transfer more gradual is to use a plate which is tapered, with the ends of the plate thinner than the mid-plate section (8,9,10). Because of the taper, the plate stiffness will be lower near the ends of the plate where most of the load transfer takes place with conventional plates.

In the present study we have used the finite element method to examine the load transfer from bone to plate for a variety of bone/plate systems.

MATERIALS AND METHODS

We analyzed a six-hole stainless steel (200 GPa) forearm plate attached to the diaphysis of a long-bone. The model has been previously described (11). Three different variations of the model were analyzed: 1) a standard plate with full-length screws (Fig. 1); 2) a standard plate with a shortened outer screw; and 3) a tapered plate with full-length screws. The tapered plate was simulated by linearly reducing the modulus of the plate elements in proportion to their distance from the mid-plate cross section. The modulus of the last row of plate elements was 21.2 GPa. A pure bending moment was applied. Models with tight interfaces (between the plate and bone and between the screw heads and the plate) and with frictional interfaces were examined.

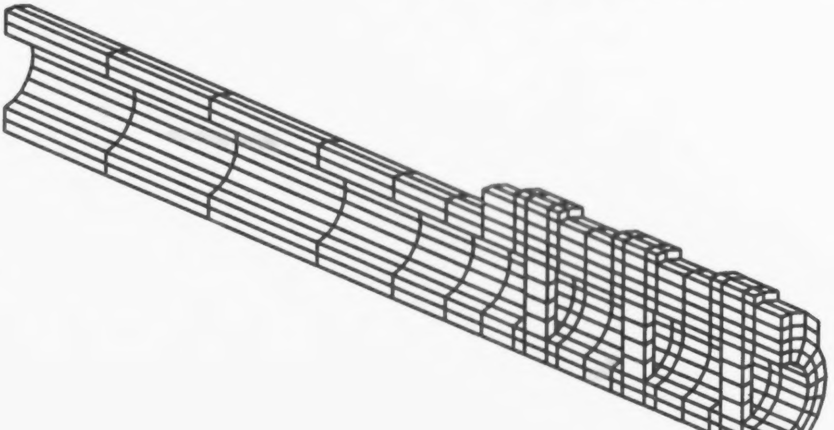

Figure 1. Quarter-symmetric finite element model (standard plate with full-length screws).

RESULTS

Tight Interface Models

Shown in Fig. 2 are the locations of the neutral axes in a longitudinal bone section taken through the plane of the screws. The neutral axes coincide at the left of the figure mid-way between the upper and lower cortex. The neutral axes shift abruptly upwards proceeding from left to right and reach their respective highest points within the upper cortex at the mid-plate cross section. The most abrupt shift in neutral axis occurred with the standard plate and full-length screws. The neutral axes for the standard plate with full-length screws and with the shortened outer screw were nearly coincident, except near the outer screw. The tapered plate produced the most gradual shift.

Frictional Interface Models

Figures 3a,b show that the shift in location of the neutral axis for the non-linear, frictional models was a function of load level. For low loads the shift was more gradual than for the tight interface models and at high load levels the shift in neutral axis location for each model was minimal.

Figures 4a,b show contours of strain energy density (SED) in a longitudinal section. Lighter regions correspond to lower values of SED. At a low level of applied load, slippage occurred more readily for the standard plate with a shortened outer screw. This created higher SED levels between the outer and middle screw. At the higher load level, slippage occurred for all three models. In this case, the distribution of the SED under the tapered plate was most similar to the normal, unplated bone.

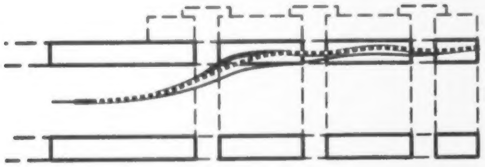

Figure 2. Neutral axis location for tight interface models.

━━━━ Standard plate with full-length screws
.... Standard plate with shortened outer screw
──── Tapered plate with full-length screws

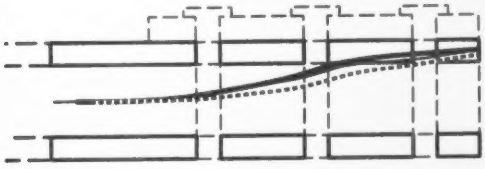

Figure 3a. Neutral axis location for frictional models (1.0 Nm).

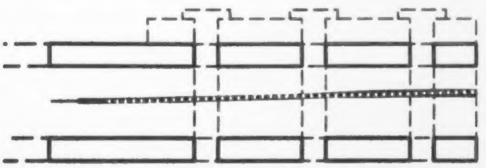

Figure 3b. Neutral axis location for frictional models (5.0 Nm).

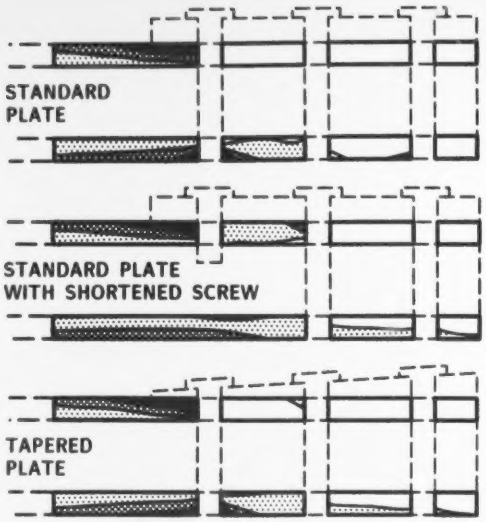

Figure 4a. Distribution of SED for frictional models (1.0 Nm).

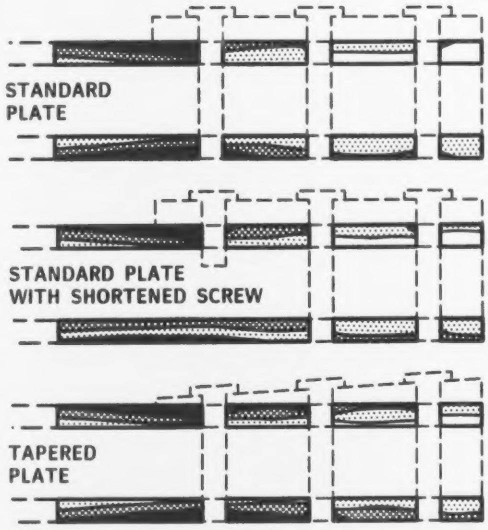

Figure 4b. Distribution of SED for frictional models (5.0 Nm).

CONCLUSIONS

In a plated bone, the transfer of load from bone to plate can be altered in a variety of ways. The use of a shortened screw or a tapered plate has been advocated. Use of a shortened screw has the potential disadvantage of providing less stability to a newly fractured bone. Since the maximum holding force which can be generated by a cortical screw is directly proportional to the length of cortex engaged, a shortened screw which engages only one cortex will only apply one half of the force of a full-length screw which engages both cortices. Tapered plates, on the other hand, rely on a decreased plate stiffness to produce a more gradual load transfer from bone to plate. This is done without jeopardizing fracture stability since all screws engage both cortices.

ACKNOWLEDGMENT

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DIFFERENTIAL DIAGNOSIS OF PATHOLOGICAL TREMORS ACCORDING TO MECHANICAL LOAD RESPONSE

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ABSTRACT

The imposition of mechanical loads on tremorous limbs and the quantification of tremor response to these externally applied conditions provides a non-invasive tool which can contribute to objective diagnoses of tremor type. The validity of this approach is demonstrated with data from experiments on two clinical subject populations -- one with *essential* tremor and the other with *intention* tremor.

INTRODUCTION

Tremor is detectable as an involuntary stochastic oscillation that is additively superimposed on volitional motor activity in both normal and pathological conditions. Abnormal tremors are readily distinguished from physiological (normal) tremor on the basis of their larger amplitude and slower frequency. Disability arises when tremor magnitude increases to the level of the concomitant volitional task, thus degrading the ability to perform activities of daily living.

The correct prescription of a rehabilitative regimen, which may include the use of assistive devices, physical therapy or medication, necessitates the accurate diagnosis of tremor type as well as its underlying etiology. In the clinic, tremor is presently evaluated as part of the neurologist's examination of a movement-disordered patient's neuromuscular coordination and strength [1,2]. Observations during the examination include an estimate of tremor frequency, a ranking of amplitude (severity) on a subjective scale, and the types of voluntary movements during which tremor is visible. Additional neuromotor deficits detected during the evaluation are also noted. This information is linked with the results of other tests to diagnose the presence of damage or degeneration to particular areas of the patient's neuromuscular system. With the diagnosis in mind, the patient's tremor is then classified.

We have proposed in an earlier paper [3] utilizing the response of the tremorous limb to mechanical loads to help identify tremogenic mechanism and to distinguish between tremor types. In this paper, we compare results from sets of mechanical loading experiments on two different clinical tremor populations, and show how, with data interpreted in light of tremor generation mechanisms, one can differentiate between two types of movement disorders that are classified by some as action tremors.

TREMOR CLASSIFICATION

Great discord remains in the terminology currently employed by practitioners and researchers to label tremors with similar characteristics (*cf.* Refs. [4,5]). One general classification system, based on concurrent voluntary motor activity in the particular muscle group or body segment is listed here. *Resting* tremor denotes the oscillations detected in a limb in the absence of voluntary muscle contraction. *Postural* tremor is seen when a limb must be supported against a constant force, such as its own weight in a gravity field. *Action* tremor is present in a limb executing a purposeful kinematic or force trajectory. Some workers in the field further define a subgroup of action tremors, called *intention* tremor, to delineate oscillations that are aggravated by the commitment of "goal-oriented" target acquisition tasks.

TREMOGENIC MECHANISMS

Tremor generation can be ascribed to three general mechanism classes summarized here. The first, the central drive model, postulates that an autonomous source in the C.N.S. drives the affected muscle groups to oscillate at a fixed frequency and amplitude, regardless of peripheral factors [*e.g.* 6,7]. The second, biomechanical resonance, proposes that the body part in question rings at a tremor frequency related to its lumped passive mechanical properties, and is forced by muscle noise that originates in a background of random motor unit firing [8]. The third, the reflex oscillator hypothesis, suggests that finite neuromuscular transmission delays reduce the phase margin of both segmental and transcortical reflex arcs, causing them to oscillate and produce tremor [9]. These tremogenic mechanisms do not have to stand alone and may interact in different proportions depending on metabolic factors, anxiety and pathology, as well as the mechanical situation in which the limb is involved.

METHODS

Subjects

The two clinical populations from which our subjects were drawn both display pathological *action* tremors -- that is, their involuntary oscillations were enhanced by purposeful movement, and the amplitudes were significantly greater and the frequencies of the visible components were slower than physiological tremor. The first group consisted of subjects with *cerebellar intention* tremor, typically associated with cerebellar systems damage. The second group had *essential* tremor, a monosymptomatic action tremor in the absence of any other neuropathic signs. Upon superficial examination, these two tremor types can overlap in terms of frequency and amplitude characteristics.

Experimental protocol

All subjects in our experiments performed pursuit tracking tasks of visually presented targets using only flexion-extension activity of the wrist. The tracking tasks are necessary to elicit volitional activity in the muscle groups being studied. During each test, external mechanical conditions (*i.e.* loads) applied to the subject's wrist were controlled by the experimenter. The mechanical conditions applied during the sets of experiments with the two subject groups are described in brief below. More detail on the rationale behind the choice of these loading schemes may be found in reference [10].

Intention tremor experiments. Two tracking cursor control modes were employed. In one, wrist flexion-extension angle was transduced by an electronic goniometer and displayed to the subject. In the other, the wrist axis of the goniometeric device was locked and isometric wrist flexion-extension torques were sensed and displayed. During the isometric tasks, the gain between the wrist torque transducer and the display was set to a different level for each test, thus requiring the subject to produce different amounts of voluntary effort to track the target excursions. These two interface modes were examined for two different forearm postures -- forearm pronated and again with the wrist flexion-extension axis vertically oriented, parallel to the action of gravity. A complete description of the apparatus and the experimental protocol is given in reference [11].

Essential tremor experiments. Both isometric torque and free-moving displacement tracking were incorporated into the essential tremor protocol with two basic modifications. First, experiments were only conducted with the wrist axis vertical. Second, different amounts of inertia were added to the subject's hand during the displacement tasks to explicitly alter limb biomechanics. The orientation of the hand and forearm during these tests precluded gravity effects (*i.e.*, heightened muscle activity needed to support greater weight) from augmenting either the equivalent joint stiffness or the muscle force variance associated with increased mean muscle tension. Greater detail on target tracking display and limb loading parameters can be found in reference [9].

Data analysis

All data gathered from these experiments were decomposed in the frequency domain into separate components comprised of the purposeful activity and involuntary tremor in the subject's response. The analysis procedure was based on the assumption that perfect, "tremorless," tracking consists of *linear* target following strategies on the part of the subject. Tremor was modelled as a stochastic noise input, uncorrelated with the target, to a linear system representation of the human tracker. A residual tremor spectrum is extracted from the overall subject response via coherence computation. Tremor frequencies and the associated peak densities are read directly from the residual spectrum. Further information on the data analysis method is given in reference [9].

RESULTS

Intention tremor load response

Seven subjects with intention tremor at the wrist due to diverse etiologies were tested under the protocol outlined above [11,12]. Their tremor spectra showed two simultaneous peaks. The visually obvious pathological tremor in the time domain was represented in the spectrum by a large magnitude peak in the 2 to 4 hz band. All subjects also displayed a small amplitude oscillation in the 8 to 12 hz band, similar in behavior to physiological tremor in terms of its linearly increasing amplitude during isometric force tasks as voluntary force was increased [13]. On the other hand, the force magnitude of the low frequency tremor was invariant for a given posture, regardless of the voluntary effort level of the particular during isometric tasks or even when unconstrained displacement tracking tasks were being performed. The frequency of the pathological oscillation was constant for both arm postures and over the complete span of interface impedances, from high stiffness isometric at different voluntary force levels down to free-moving displacement situations. This invariance of tremor characteristics over the wide range of peripheral factors examined ruled out both biomechanics and reflex loop activity as tremor sources. By default, an autonomous central drive, the remaining of the three tremogenic models, was accepted as the generating mechanism of pathological intention tremor.

Essential tremor load response

Nine subjects with essential tremor at the wrist were studied [14]. Two simultaneous peaks were again evident in this subject group's tremor spectra. Comparisons across the two different tracking task types for these subjects, though, did not show the invariance of tremor frequency and force characteristics demonstrated in the intention tremor group. During the *isometric* tests both the low frequency, large amplitude (4 to 7 hz) and high frequency, small amplitude (8 to 12 hz) components increased in magnitude as greater levels of voluntary force were demanded of the subjects. During the *displacement* tracking tasks, the slower oscillations decreased in frequency as the inertia of the hand was augmented; the frequency of the faster tremor was unaffected. The responses of both oscillations in these tremor spectra to changes in voluntary isometric effort points to the role of peripheral factors in essential tremor generation. The resultant shift of only the slower oscillations in the response to changes in inertia implied that only the large-amplitude (4 to 7 hz) components of the tremor were sensitive to biomechanics while the higher frequency ones were not. Considering the three general tremogenic mechanism models discussed earlier, the source of the faster small amplitude oscillation is narrowed down to a reflex loop oscillator. The slower, pathological tremor is clearly governed by biomechanical factors. The participation of a reflex factor in the slower oscillation cannot be resolved from our data.

CONCLUSIONS

At this stage, with data reduced from two separate studies, we are able to discern the difference in the responses of two clinical tremor types to externally applied mechanical conditions. Interpreting the results from these experiments, with the goal of identifying the underlying tremor generation mechanisms, allows us to distinguish between centrally driven *intention* tremor and biomechanically mediated *essential* tremor

The expansion of this work to cover many other clinical tremor groups, and to study them in greater detail under a wider variety of external limb loading conditions, will permit a more detailed list of tremor characteristics to be catalogued. Once such a catalogue is developed, well controlled mechanical loading protocols may contribute to a more precise test battery for tremor diagnosis.

ACKNOWLEDGEMENTS

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BIOMECHANICAL MODELING OF THE CHIARI HIP OSTEOTOMY

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ABSTRACT

Since its introduction by Chiari in 1955, the medial displacement osteotomy of the pelvis has become widely used as a treatment for hip dysplasia. Although the Chiari osteotomy relieves most patients' pain, many are left with a long-term limp.

Our experimental hypothesis was that surgical modification of the musculoskeletal geometry may substantially reduce hip joint abductor torque and thus produce the limp. To test this hypothesis, we developed a computer model that generates the post-surgery hip joint geometry given values for three surgical parameters: angulation of the osteotomy, length of medial displacement, and angle of internal rotation. Additionally, the model computes maximum isometric hip abductor torque both before and after surgery.

We found that some sets of surgical parameter values conserved abductor torque while others greatly reduced it. Large angulation combined with large medial displacement reduced abductor torque by up to 65 percent and may account for the limp.

INTRODUCTION

In 1955, Karl Chiari described a pelvic displacement osteotomy for treating congenital subluxation of the hip [1]. In this procedure a cut is made through the iliac bone, dividing it into two pieces. The distal bone fragment is then displaced and repositioned medially to create a bony ceiling above the femoral head (Figure 1). Increased femoral head coverage provides better structural support and hence improves hip joint stability. The operation is now used at many centers throughout the world to treat hip dysplasia [2].

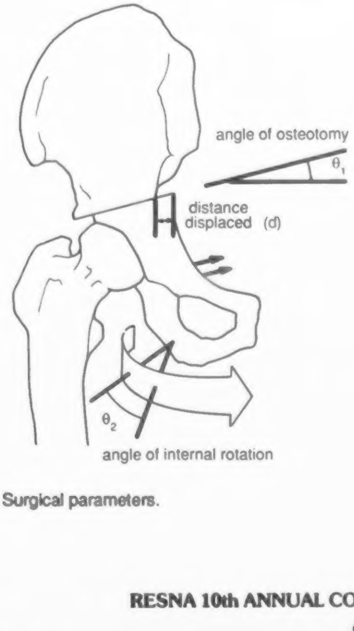

Figure 1. Surgical parameters.

Although the Chiari osteotomy relieves most patients' pain, many are left with a distinct and long-term limp [1] [3]. The limp (Trendelenburg gait) occurs when the hip abductors are not able to counteract the torque due to gravity (Figure 2). Hence, the pelvis sags during single leg stance. Our experimental hypothesis was that surgical modification of the musculoskeletal geometry may substantially reduce hip joint abductor torque and thus cause the limp. To test this hypothesis we developed two specific goals:

(1) To develop a surgical model which computes the post-surgery hip joint geometry given values for the surgical parameters,

(2) To quantify the changes in hip abductor torque resulting from the changes in musculoskeletal geometry.

We report here our method of analysis and preliminary results.

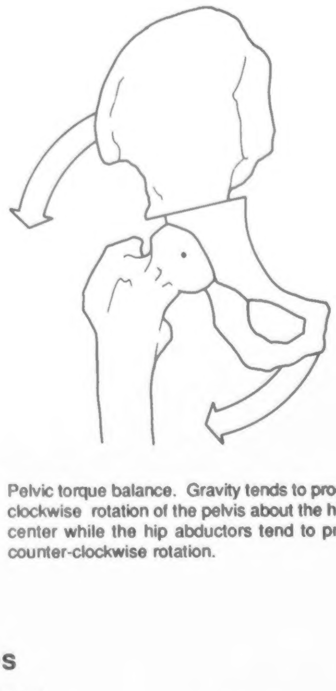

Figure 2. Pelvic torque balance. Gravity tends to produce a clockwise rotation of the pelvis about the hip joint center while the hip abductors tend to produce counter-clockwise rotation.

METHODS

Surgical Model

The surgical procedure was modeled by three geometric parameters: angulation of the osteotomy (θ_1), distance of medial displacement (d) and angle of internal rotation (θ_2) (Figure 1). To compute changes in the musculoskeletal geometry, surgical parameter values were specified within clinically reasonable ranges ($0° \leq \theta_1 \leq 30°$; $0 \text{ mm} \leq d \leq 30$ mm; $-20° \leq \theta_2 \leq 20°$). It was assumed that the proximal fragment of the ilium remained fixed while the distal portion was displaced. Hence, the output of the surgical model included post-surgery muscle insertions and a new hip joint center, while the muscle origins remained unchanged.

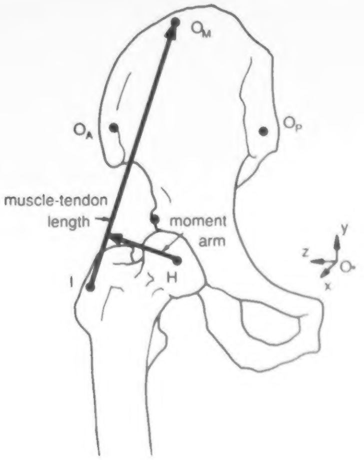

Figure3. Musculoskeletal coordinates for the gluteus medius. O_A, O_M, O_P represent anterior, medial, and posterior muscle origins. I represents the muscle insertion. H is the hip joint center. O* is the origin of a fixed coordinate system. Muscle-tendon length and muscle moment arm can be computed from these coordinates.

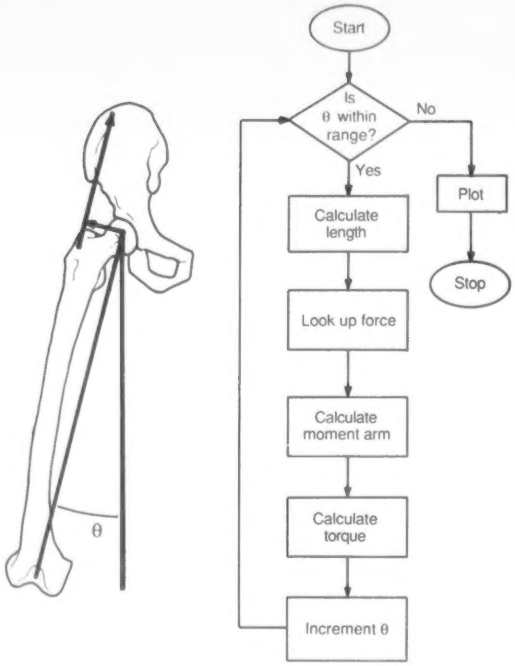

Figure 4. Procedure for computing abductor torque vs. abduction angle.

Musculoskeletal Model

Coordinates for the three primary hip abductor muscle origins and insertions were taken from data reported by Brand *et. al.* [4] and were expressed in a fixed coordinate system. The gluteus minimus and tensor facia latae were modeled as single lines from origin to insertion, while the gluteus medius was broken into three separate lines representing posterior, medial, and anterior aspects (Figure 3). To compute abductor torque, we first calculated the length of each musculotendon actuator as the magnitude of the vector from origin to insertion. We then used a model for each musculotendon actuator [5] to find the muscle force. Knowing muscle force we computed abductor torque as a vector cross product [6]. This procedure allowed us to compute maximum isometric abductor torque both before and after surgery (Figure 4).

In order to validate the simulated hip abductor torque, we compared the torque computed for the three primary hip abductors with experimentally measured data [7]. Figure 5 shows the close correspondence between computed and measured hip abductor torque. These curves also show that the gluteus medius provides about 70 percent of the total abductor torque near anatomical position (0° of abduction). Since the hip operates between ±10° of abduction during gait, our preliminary results focus on the gluteus medius.

Simulations of Surgery

To initiate a surgery simulation, we input values for each surgical parameter. The surgical model then computed the post-surgery hip joint geometry. These intermediate results were input to the musculoskeletal model where post-surgery gluteus medius abductor torque was computed for joint angles ranging from -15° to 50° of abduction. Both pre-surgery and post-surgery torques were then plotted vs. joint angle.

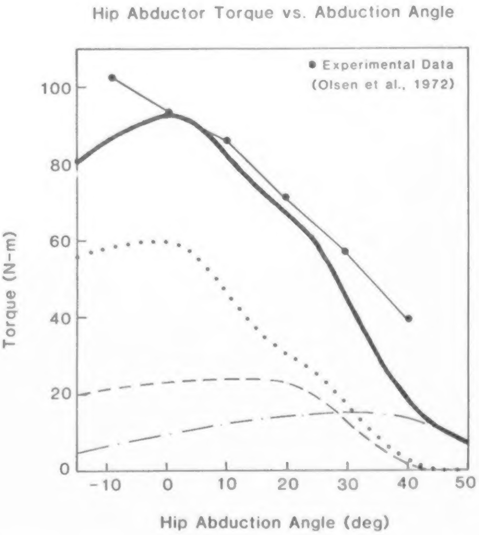

Figure 5. Comparison of computed and experimental hip abductor torques Tensor facia latae (dashed dotted line) gluteus minimus (dashed line), gluteus medius (dotted line), sum of computed torques (solid line) experimental data (segmented line).

RESULTS

We found that some sets of surgical parameter values conserved gluteus medius abductor torque while others largely reduced it. For example, with 15 mm of medial displacement, -5° of angulation, and 10° of internal rotation, post-surgery abductor torque was reduced by only 10 percent at anatomical position (Figure 6). In contrast, with 30 mm of medial displacement, 30° of angulation, and 10° of internal rotation, post-surgery abductor torque was reduced by 65 percent at anatomical position (Figure 7).

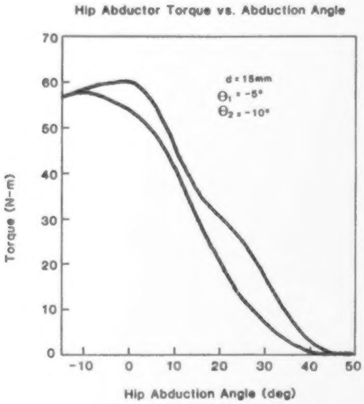

Figure 6. Results of a surgery simulation showing conservation of abductor torque. Pre-surgery gluteus medius abductor torque (upper curve). Post- surgery gluteus medius abductor torque (lower curve).

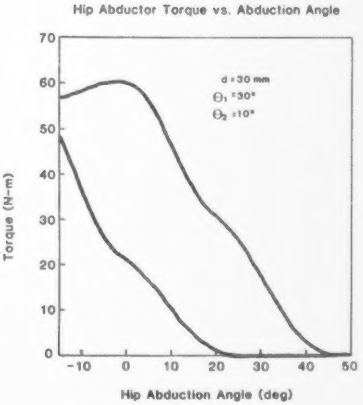

Figure 7. Results of a surgery simulation showing largely reduced abductor torque. Pre-surgery gluteus medius abductor torque (upper curve). Post-surgery gluteus medius abductor torque (lower curve).

Changes in abductor torque results from change in either muscle force or change in muscle moment arm. Muscle force is a function of muscle length so we must consider how the surgery changes the pathlength (origin to insertion length) of the musculotendon actuator. Since the gluteus medius operates in the ascending region of the force-length curve for muscle, any decrease in the pathlength for origin to insertion causes a decrease in muscle force (torque) at a given angle of abduction. As the angle of the osteotomy is increased the pathlength is decreased. Furthermore, increasing the length of medial displacement also reduces pathlength. Surgical simulations with both large angulation and displacement resulted in greatly reduced abductor torque.

Angulation and displacement had minimal effect on muscle moment arm while internal rotation had a large effect. The maximum frontal plane moment arm occured at about fifteen degrees of internal rotation. Internal rotation lengthened the path of the posterior aspect of the gluteus medius while shortening the path of the anterior aspect. External rotation had the opposite effect. The changes in abductor torque due to moment arm effects were small compared to those caused by the change in muscle length.

CONCLUSIONS

A mathematical model of a Chiari osteotomy allows us to compute the post-surgery hip joint geometry and the corresponding changes in hip abductor torque. Reduction in gluteus medius abductor torque occured primarily from shortening the muscle path. We found that simulated surgeries with large angulation and large medial displacement reduced the post-surgery abductor torque by up to 65 percent -- enough to cause a limp. By choosing surgical parameter values that conserve abductor torque, the limp may be avoided.

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EVALUATION OF POSTURE AND BALANCE IN CEREBRAL PALSIED CHILDREN

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Abstract: The purpose of this study was to develop a technique to provide an objective quantitative evaluation of posture and balance and to demonstrate the potential clinical usefullness of this technique. The clinical population selected for study was a group of children with cerebral palsy. In order to quantify posture wholebody kinematic data was acquired using a bilateral Selspot/TRACK system. Balance was quantified using bilateral Kistler piezioelectric force plates. Kinematic indices based on joint flexion angles, joint angle change and joint flexion moments were evaluated as means for summarizing the kinematic data and as possible clinically useful quantitative measures of posture. Balance was quantified using the standard deviation of the center of pressure location as determined from the bilateral forceplate measurements.

Introduction: The purpose of this study, carried out at the MIT Newman Laboratory of Biomechanics and Human Rehabilitation and at the MGH Biomotion Laboratory, was to develop a technique for quantitatively and objectively evaluating posture (the alignment of the body segments) and balance (the control of the position of the center of gravity, CG). The clinical population selected for study was a group of children with cerebral palsy (CP) clinically evaluated as having postural deformity and/ or balance deficits. The study was intended to demonstrate the potential usefulness of the technique in providing objective quantitative measures of postural deformity and balance deficit. The study also attempted to demonstrate the potential usefulness of this technique as a means of evaluating the effectiveness of interventions intended to improve posture and/or balance. A limited number of studies, using mainly force platform and EMG data, have addressed the problem of balance in children afflicted with cerebal palsy [1,2]. No studies, to our knowledge, have looked specifically at posture as we define it.

Posture was quantified using a bilateral Selspot/TRACK system[3]. The body was modelled using eleven body segments each having a full six degrees of freedom. A 3D computer graphics display of the results including the simultaneously measured ground reaction forces provided a tool for qualitative visual evaluation of posture. Two forms of this display were developed, a hardcopy summary graphic [Figure 1], and a 3D interactive computer graphics display which permitted each set of kinematic data to be displayed at whatever rate desired including stopping and backing up to repeat specific frames of data. The graphics were designed to enhance the clinician's subjective evaluation of posture.

Kinematic posture indices were used to achieve the objective quantitative evaluation of posture. Three kinematic indices based on joint flexion angles, ranges of active motion, and net joint flexion moments were considered. In addition, balance was quantified using the standard deviation of the combined center of pressure location. The use of two force platforms (one under each foot) facilitated the identification of assymetry.

Methods: Seven CP subjects, aged 7 to 17, were selected for study. Four patients were classified as spastic quadriplegic, two as spastic diplegia and one as a spastic hemiplegic. All were able to stand without braces or supports for at least 90 seconds, and had normal or corrected normal vision and normal hearing. Six age-matched controls were also selected for study.

Two sets of tests were used to evaluate posture and balance. Posture was evaluated using a series of five second duration tests during which kinematic and force plate data were aquired. These tests evaluated posture for stance: 1)unaided, 2)with tactile reference(light touch), 3)with audio feedback(coaching), and 4)with ankle-foot orthoses(AFOs). These tests were performed with and without blindfolds. The ability to respond to disturbances was also evaluated with surprise and then alerted passive disturbances and during a voluntary rapid right arm raise.

Balance was evaluated using a series of longer (90 second) trails in which force platform and limited EMG data were aquired. These tests evaluated balance for stance: 1)unaided, 2)with tactile reference, 3)with audio feedback, and 4)with AFOs; again with and without blindfold.

Three kinematic indices were calculated from the kinematic and force plate data: a flexion angle index (ANG), a range of motion index (ROM), and a joint flexion moment index (MOM). These indices are defined in Table 1. They summarize the comparatively massive amount of kinematic data acquired in each trial and characterize posture with several objective quantitative parameters. ANG represents the sum over the joints of interest of deviation of the flexion angle from normal (taken to be 0 deg). ROM is the sum over the joints of interest of the difference between the largest and the smallest flexion angle observed during a standard trial. MOM is the sum of the absolute value of the joint flexion moments divided by the subject height and weight, a normalized joint flexion moment arm. The parameter used to quantify balance was the standard deviation of the combined center of pressure location (SDCP).

Results: Tables 2, 3 and 4 show typical values of the angle index, range of motion index and moment index for normal, diplegic, hemiplegic and quadraplegic subjects. Table 5 shows the balance index results for the same subjects. The kinematic indices permit quantitative discrimination of the level of postural abnormality. ANG and MOM are measures of the abnormality of the person's mean position. ROM is a measure of the stability of posture. SDCP is a measure of the stability of balance. ROM and SDCP contain related but not identical information.

Table 6 presents ANG for two subjects of similar age, sex and size for several test conditions. The test conditions evaluated are normal stance eyes open, tactile reference eyes open, audio feedback eyes open and AFOs eyes open. The ability to discern the effects of these interventions is indicated.

Discussion: Selspot/TRACK kinematic data have been used to quantitatively and objectively characterize posture and balance. This involves the determination of the position and orientation of eleven body segments. Kinematic indices have been used to extract a subset of the information from the basic data in a summary form. Review of the preliminary data indicates that the kinematic indices are sufficiently sensitive to permit objective quantitative discrimination of the level of postural abnormality. It is also possible to measure the effect of posture correcting interventions in a way which will permit objective evaluation of results.

The ROM index contains information related to the subject's response to active and passive disturbances. It is also possible to compare magnitude of the center of pressure excursion during and following disturbances. However, neither of these techniques seems to adequately characterize postural control stratagies or balance. This is an area of ongoing research.

The objective quantitative evaluation of posture and balance is important for three reasons. First, more precise diagnosis of the patient's postural abnormality and/or balance deficit is established. Second, the effect of interventions intended to improve posture or balance can be objectively evaluated. This will improve individual patient therapy aiding clinical determination of which interventions are effective for the individual. It will also improve treatment in general by providing objective evaluation of the effectiveness of interventions on large patient populations. Thirdly, this technique should promote new approaches to basic research in posture, posture control and balance.

Table 1

Kinematic Indices Definitions

$$\text{ANG} = \sum \left| (\text{Flexion angle} - 0.0) \right|$$

$$\text{ROM} = \sum \left| (\text{Flexion angle}_{\text{max}} - \text{Flexion angle}_{\text{min}}) \right|$$

$$\text{MOM} = \sum \frac{\left| \text{Flexion moment} \right|}{\text{Weight*Height}}$$

Table 2

Angle Index ANG
(typical values, degrees)

Control	24.8
Diplegic	73.7
Hemiplegic	87.5
Quadraplegic	134.8

Table 3

Range of Movement Index ROM
typical values, degrees)

Control	26.4
Diplegic	25.0
Hemiplegic	59.3
Quadraplegic	69.5

Table 4

Moment Index MOM
(typical values, mm/m)

Control	75.8
Diplegic	84.5
Hemiplegic	102.7
Quadraplegic	125.3

Table 5

Balance Index SDCP
(typical values, mm)

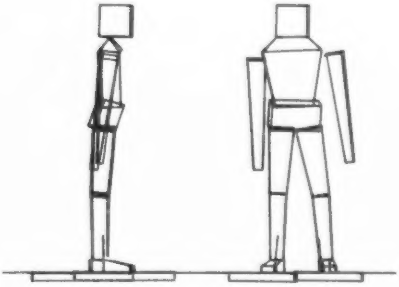
Control	5.7
Diplegic	5.7
Hemiplegic	8.8
Quadraplegic	18.1

Table 6

Angle Index ANG

Subject	LMB	VMR
Group	Control	Quad
Condition		
NSEO	57.8	155.1
TREO	55.1	172.1
AFEO	70.9	155.8
AFOEO	54.3	120.1

Figure 1



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EPIPHYSEAL REPLACEMENT PROSTHESIS

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ABSTRACT

Conventional total hip arthroplasty is a highly successful surgical procedure for treatment of severe arthritis of the hip. However, the incidence of mechanical failures in the form of femoral component loosening and stem fracture has become an increasingly significant problem, especially in younger patients, and has renewed interest in conservative alternatives. One such alternative is the Epiphyseal Replacement Prosthesis, a new research-based design which incorporates the interface contours suggested by the geometry of the epiphyseal plate or scar. Finite element stress analyses have shown that interface contours of this geometry transfer stresses from the prosthesis to the bone in a much more natural manner than previous designs. Animal studies are now being planned to verify the theoretical model and to provide an in vivo biological and clinical evaluation.

INTRODUCTION/ BACKGROUND

It was hoped that total hip surface replacement would be ideally suited for younger patients. The theoretical benefits of total hip surface arthroplasty are the provision of a functional hip joint with a minimum removal of healthy bone. This would lead to a more natural stress distribution in the post-operative hip and simplify re-operation if it were required. Unfortunately, the failure rates of many types of hip surface replacements have been disappointingly high. The causes of failure have been attributed to stress concentration effects, stress shielding effects, micro-motions of prosthesis, and vascular effects.

DESIGN METHODS

Stress Shielding Elimination

The stress shielding problem is a direct result of the deep shell design of surface replacements. The rigid metal shell destroys the normal pattern of stress transmission in the femoral head. The surface forces are transmitted through the shell to its rim and then in a concentrated manner to the bone at the edge of the implant. The trabecular bone directly under the shell which would carry the load in an intact joint is stress shielded. The addition of a central peg to the shell does not alleviate this stress shielding since the peg tends to transmit the load to the inferior aspect of the femoral neck (1,3). This stress shielding can lead to a vicious cycle where the stress shielding causes cancellous bone resorption which in turn causes further stress shielding, leading eventually to total failure of the implant (3).

One means of alleviating the stress shielding problem is to redesign the bone/prosthesis interface such that the stress is transferred to the bone in a more natural manner (1). A naturally occurring surface which has the potential of being a good interface is the epiphyseal surface of the proximal femur (1,2). Since the epiphyseal plate in young people is composed of cartilage, which is weak in shear relative to cancellous bone, the stress transmission across this surface is due primarily to normal pressure and tension. If the bone/prosthesis interface of a porous ingrowth surface replacement is designed to be similar in shape to the epiphyseal plate, a more normal transmission of stress to the bone may result. This is the basis of the Epiphyseal Replacement Prosthesis.

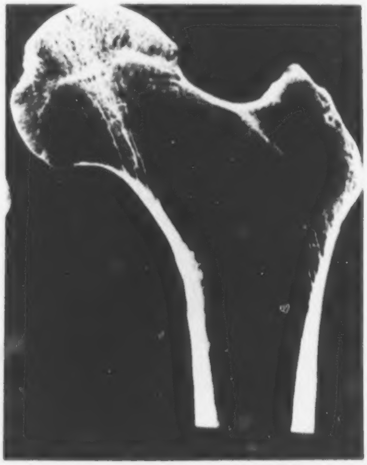

Figure A. Cross-section of femoral head showing epiphyseal line and trabeculae structure

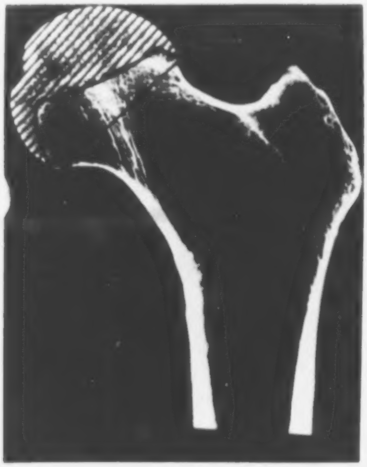

Figure B. Cross-section of femoral head and attached Epiphyseal Replacement Prosthesis

EPIPHYSEAL REPLACEMENT PROSTHESIS

The Epiphyseal Replacement Prosthesis was designed in an effort to minimize load sharing and to provide for a direct transmission of force through the implant to the bone tissue. The principle employed is essentially that implants should be designed in such a way as to present series mechanical loading between the implant and the bone rather than parallel type loading or load sharing. This series type of force transfer will tend to maintain the stress levels in the bone at a more normal physiological level, and also reduces the magnitude of the shear stresses at the interface. A comparison of figures A and B reveals that the bone/prosthesis interface of the Epiphyseal Replacement Prosthesis does indeed closely follow the line of the epiphyseal plate and is perpendicular to the main stress bearing column of compressive trabeculae, thus promoting series mechanical loading.

Finite Element Analyses

Finite element stress analyses were conducted on femoral heads before and after the implantation of an epiphyseal replacement prosthesis (see figure C). The new epiphyseal replacement design resulted in stress distributions similar to those in the normal femoral head and in minimal shear stresses at the bone/prosthesis interface (4). These findings suggest that the Epiphyseal Replacement Prosthesis may provide better initial mechanical integrity and create a more favorable environment for adaptive bone remodelling than the conventional shell-type surface replacement components. Further finite element stress analyses involving adaptive bone remodelling of the proximal femur with and without both the conventional shell-type surface replacement and the Epiphyseal Replacement Prosthesis are now being performed.

Fixation Techniques

The Epiphyseal Replacement Prosthesis may be fixed to the femoral head either through the more conventional use of bone cement or through the use of bony ingrowth surfaces. The bony ingrowth surface provides a tight bond between the metal and the bone which efficiently transfers the interface stresses. If bony ingrowth were the desired fixation technique, a set of 1.5mm diameter spikes would be incorporated into the prosthesis at the bone/prosthesis interface to provide for firm initial fixation and to prevent micro-motions of the prosthesis. These spikes are of small enough diameter and length to avoid transmitting the load along their lengths to the bone. Further testing is being conducted to determine the strength of the spikes and the exact number needed for the prosthesis. Simple instrumentation has been designed for implant installation.

ANIMAL STUDIES

Before implanting the epiphyseal total hip replacement prosthesis in humans, we propose to perform an animal study on sheep. On the basis of the results of the animal project, we would then decide whether or not to implant these prostheses in patients. The animal study would verify the theoretical model and would be an in vivo biologic and clinical evaluation.

The animal project would consist of implanting the epiphyseal total hip replacement prosthesis into sixteen sheep; one per sheep. Eight of the prostheses would be cemented and the other eight would be placed for porous ingrowth. The animals would be serially sacrificed over a period from six weeks to one year. At the time of sacrifice, the proximal femur and hemipelvis would be extracted and contact x-rays made. Thereafter, appropriate histologic sectioning of the bone prosthetic interface would be obtained. Comparison would be made of the prosthesis between the two types of fixation. Additional comparisons would be made from our experimental results and those of the literature with other prostheses.

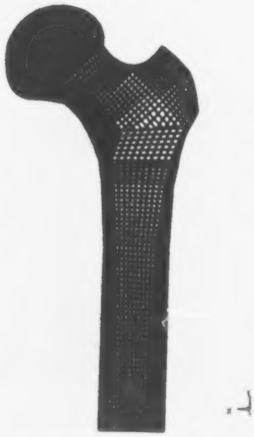

Figure C. Finite element model of femoral head

CONCLUSIONS

New finite element stress analysis models suggest that a femoral prosthesis which incorporates an interface contour similar to that of the epiphyseal scar may transfer stresses from the prosthesis to the bone in a much more natural manner than previous unsuccessful surface replacement designs. This is the basis for the Epiphyseal Replacement Prosthesis. Should the planned animal studies verify the theoretical model, these new finite element stress analysis models could prove to be invaluable in reducing the number of iterations involved in joint prosthesis design.

ACKNOWLEDGEMENTS

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THE DEVELOPMENT AND TESTING OF AN ISOKINETIC STRENGTH TESTING DEVICE

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ABSTRACT

The success of any screening or work capacity program requires accurate information on actual job demands as well as precise measurements of worker capacities related to key job demands. A device has been designed, fabricated and tested that can measure a person's whole body strength. The present study documents the repeatability of testing a person's vertical lifting strength isokinetically. Lifts were performed by 5 male subjects over the course of 3 days. None of the variables had an effect on measured strength, with the exception of height of the lift, which was significantly related to generated force. Isometric strength values were, on the average, 37% greater than the isokinetic values determined for the same height. Output can be depicted as iso-strength lines depicting a person's whole body lifting strength throughout his range of motion.

INTRODUCTION

Low back pain is mankind's most common musculoskeletal complaint, the greatest source of compensation payments, and is the second most common cause of work loss (5). Epidemiologic studies (2,3,4) have shown that 40-80% of the adult population will experience low back pain at some time during their life. The result in terms of economic impact in the United States alone is estimated to be in excess of 20 billion dollars per annum.

Muller (9) indicated that the object of determining work capacity of the worker in the workplace is to fit the job to the worker so that he can work without fatigue or harm to his health. When considering an injured worker this becomes extremely important in the successful rehabilitation process. Success of any screening or work capacity program requires accurate information on actual job demands as well as precise measurements of worker capacities related to key job demands.

The literature abounds with techniques and methods for isometric, isotonic and isokinetic strength testing. The NIOSH Work Practices Guide for Manual Lifting (14) recognized isometric strength testing as a resonable way to identify workers who might be at a higher risk of low back pain or overexertion injury. However, Mayer et al. (8) point out that isometric muscle activity is usually associated with higher rates of injury than dynamic activity. Pytel et al. (12) and Kroemer (6) have criticized isometric strength testing because it does not reflect the fact that lifting is a dynamic activity. Marras et al. (7) states that isometric strength testing can be misleading and endorses an isokinetic approach. He suggests that isokinetic evaluation is a more realistic procedure for evaluation of tasks related to manual material handling conditions. Isokinetic testing allows measurement of the actual force output capability at every point along the lifting arc.

The purpose of this study was to determine the repeatability of a method of measuring isokinetic vertical lifting strength.

METHOD

Subjects: The test group consisted of five male subjects between the ages of twenty-three and thirty-five. No subject had a previous history of low back injury, pathology or surgery and were recruited for participation based on these criteria. All subjects worked at a sedentary job or school, and participated in various types of recreational activities. Prior to the initial testing, each subject read a laymen's summary of the experiment and test protocol and signed a consent form. Table 1 lists the age, height, weight and arm length for the five male subjects. Paired t-tests showed no significant differences among these factors between individuals ($p<0.05$).

TABLE I: SUBJECT INFORMATION

AGE (years)	28.8 +/- 5.3
HEIGHT (inches)	70.8 +/- 1.3
WEIGHT (pounds)	170.0 +/- 3.5
ARM LENGTH (inches)	26.0 +/- 1.2

Apparatus: A physical evaluation device was designed and fabricated that can test a person's maximum isokinetic strength from any direction, without inhibiting range of motion. A dynamometer (Cybex II, Lumex Inc, New York) provided the main source of isokinetic resistance for the device. Through a number of fixed and adjustable pulleys force can be applied to a cable attached to a handle. The speed range for the device can range from no movement, as in an isometric test, to 5 ft/sec of linear motion. Forces were measured at the handle by a strain gauged load cell, in order to bypass any frictional forces inherent in the device. A potentiometer connected directly to the drive system measures the displacement of the cable. Both of these instruments output a voltage which is linearly proportional to the quantity being measured. The load cell and potentiometer are connected to a microcomputer (IBM PC) via an analog to digital converter (Data Translation Board).

Procedure: Each test session for a subject consisted of two sets of five vertical lifts, in the mid-sagittal plane, floor to head height at each of two horizontal distances from the lifting handle at a test speed of 12 inch/second. One minute rests between lifts and five minute rests between bouts were given to eliminate fatigue. The two horizontal distances were determined as a percentage of the subject's arm length as measured from the acromion process to the first

metacarpal-phalangeal joint. At the completion of the the isokinetic tests each subject rested five minutes then, lifted isometrically at the height of peak exertion as assessed by the isokinetic data. Three five second isometric lifts were completed for each distance; 90% arm length first then 30% arm length. Each subject completed three test sessions within a seven day period, allowing only one session per day. Each test session lasted approximately one hour. Subjects were questioned concerning muscle soreness and comfort after each session and prior to the following session. No subject verbalized discomfort during or after lifing. Subjects were instructed to lift vertically as hard and as fast as possible while maintaining their feet positioning. Any lifting technique was acceptable and subjects were given a period of time before each session to become familiar with their technique and the machine. This warm-up period typically consisted of five to ten lifts. Once the lifting technique was chosen, subjects were requested to utilize that technique throughout the testing procedure. A video camera and recorder was used to tape each subject's lifting technique.

RESULTS

Statistical analyses of the data were made using a within subjects, completely crossed ANOVA program. The dependent variables were the force values at each of five heights (14.3%, 34.3%, 54.3%, 74.3% and 94.3% maximal height). The two horizontal distance groups were analyzed independently; 30% and 90% arm length. This repeated measures model tested for daily differences as well as differences between repetitions, sets of repetitions (bouts) or interactions between these measures for each individual. A summary of the ANOVA results are presented in Table 2. Using a t-test, a significant difference was found between the isokinetic force values at the two horizontal distances ($p<0.001$). At both horizontal distances only height of lift was found significant (30% arm length $p<0.03$; 90% arm length $p<0.001$)

To determine test-retest reliability, a correlation was tested between the force values for each individual at each of five heights for Bout 1 at two horizontal distances between Days 1, 2 and 3 (N=50). Correlation coefficients were found to range from 0.833 to 0.912. A complete listing of correlation coefficients with Days can be found in Table 3.

The isometric force value was found to be significantly larger than the isokinetic force measurement ($p<0.001$) at the same location. Interestingly, when the isokinetic force was examined as a percentage of the peak isometric force the mean was 73.19% +/- 3.05% SE.

A Computer program has been developed which utilizes the force values at four horizontal distances (30%, 50%, 70% and 90% arm length) to construct a two-dimensional strength field model for an individual. A sample contour plot is depicted in Figure 1.

TABLE 2: Analysis of Variance (ANOVA) Results for 30% and 90% Horizontal Arm Length

Source	**Degrees of Freedom**	**Tail Probability**	
		30%	**90%**
D	2,8	0.1926	0.0998
B	1,4	0.0564	0.9062
DB	2,8	0.6177	0.2298
R	4,16	0.4702	0.6880
DR	8,32	0.5784	0.0808
BR	4,16	0.2354	0.2633
DBR	8,32	0.3295	0.3777
H	4,16	0.0322*	0.0001*
DH	8,32	0.5797	0.1011
BH	4,16	0.2556	0.1920
DBH	8,32	0.4297	0.3668
RH	16,64	0.9797	0.2541
DRH	32,128	0.9280	0.8265
BRH	16,64	0.4864	0.8280
DBRH	32,128	0.8847	0.5410

*significant values
(D=Day 1,2,3; B=Bout 1,2; R=Repetition; H=Height)

TABLE 3: REPEATABILITY OF BOUT 1

Day 1 vs Day 2	r = 0.833
Day 2 vs Day 3	r = 0.912
Day 1 vs Day 3	r = 0.875

DISCUSSION

Although a number of studies have used devices which test trunk muscles as isolated functional groups to assess trunk strength isokinetically and isometrically, few have attempted to examine isokinetic and isometric strength through a functional lifting task. Smidt et. al (13) have suggested that the isolated testing of muscle groups may not provide information adequate to identify the "weak link" in the system. The present lift testing device addresses "whole body" lifting strength. Therefore trunk, as well as, arm, shoulder, leg and chest musculature important in lifting in the workplace, are tested.

ANOVA results report the only significant difference was that found among the force values at different heights. Recognizing that a person's strength is different throughout his range of motion, it is extremely important to identify where in space the lift will occur. In general, a person is strongest when lifting close to his body and around his knees. People with low back pain or other disabilities may demonstrate unique patterns of strength that can then be assessed in light of the job requirements.

The present device has proven to be a repeatable test of a person's lifting strength. No significant differences were found between Days or Repetitions for either horizonal distance. The correlation coefficients determined for the force values at each of five heights for Bout 1 between Days 1, 2 and 3 (N=50) suggest high test-retest reliability. Therefore, using one bout in one day of testing will give reliable force measurements indicative of an individual's force production.

It is interesting to note that at the 30% arm length distance, the differences between Bouts approached significance ($p<0.0564$; df=1,4). Cell mean values were averaged over Day and Repetition calculating an average force value for Bout 1 as 92.5lbs., and Bout 2 as 95.8lbs. It appears that the higher force value for Bout 2 is due to a warming up effect rather than a training effect due to lack of significance of the Bout vs Day interaction.

The significant difference between the isometric force measurements and the corresponding isokinetic values suggest that the isometric values being used presently to assess the maximal strength ability of the worker in the workplace may be overestimating the strength capabilities of that worker. Isokinetic values which, on the average are 73% of the corresponding isometric measurement, suggest that when moving at a speed of 60 degrees/second (12 inches/second) an individual can not generate the force that can be generated during an isometric (0 degrees/second) contraction. This would support the findings of Murray et. al (10) and Osternig et. al (11) who reported that as the speed of contraction increases the force generated decreases. Marras et. al (7) suggested isometric lift testing may be overestimating the functional strength capabilities of the worker.

The pattern of the iso-force bars constructed with the isokinetic data appear to correlate well with the pattern described by Chaffin et al (1) using a theoretical biomechanical model.

Due to the of the specific statistical design utilized in this paper, the force values are compared with each other at specific heights which enables the researcher to, in effect, analyse the goodness of fit between force generated curves. Repeatability of force curve generation is often used as a way of identifying malingerers. Those subjects not able to recreate a force curve are thought not to be giving a maximum effort. However, there is a great deal of subjectivity and difficulty in interpreting this data. Previous researchers have relied on the area under the curve to compare graphs, or basically "eyeballing" the curves. The present method of gathering data at specific heights provides an objective means of comparing force values while directly relating those values to points on the curve.

CONCLUSIONS

A device has been designed, constructed and tested that measures a person's whole body isokinetic lifting strength. Tests have shown the device to be repeatable over 3 days. The output of the device is a contour plot describing the person's strength throught his range of motion. It was also found that isometric strength testing reported values of strength that were significantly higher than those reported from the isokinetic testing.

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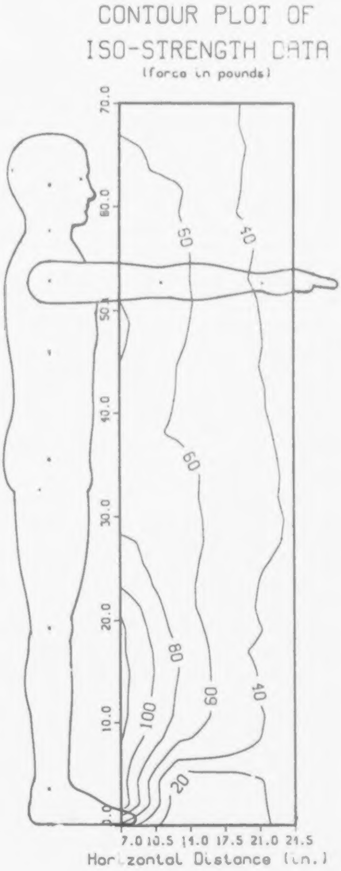

THE EFFECTS OF PATELLAR SIZE AND PATELLAR LIGAMENT LENGTH ON KNEE JOINT MECHANICS - IMPLICATIONS FOR REHABILITATION

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ABSTRACT

A planar, quasi-static model of the knee joint was developed in order to calculate effective extensor moment arms for the quadriceps muscle. In the model, the relative orientation of the femur to the tibia accompanying knee flexion was prescribed to match that reported in the literature. Nonlinear force and moment equilibrium equations were then solved to yield patellar orientation, patellofemoral contact force, and patellar ligament force and direction for flexions ranging from 0 (full extension) to 90 degrees. Variations in patellar thickness, length, and patellar ligament length were found to affect these calculations, which subsequently altered the effective moment arm of the quadriceps muscle. Increasing the thickness of the patella increased the effective moment arm significantly only at flexions less than 35 degrees, while increasing either the patellar or patellar ligament length increased the effective moment arm significantly only at flexions greater than 25 degrees. These results illustrate the mechanical operation of the patella primarily as a spacing device at low flexions and predominantly as a levering mechanism at moderate to high flexion angles.

INTRODUCTION

Our interests in human movement, posture, and coordination have naturally led to the study of joint moment arms. Unfortunately, the knee, being especially important, is complex. Since the quadriceps develops large extensor forces about small moment arms to create joint torques, small changes to the extensor moment arm can lead to large changes in torque. Hence, limb extension may be severely compromised by surgical techniques (*e.g.* patellectomy, total knee replacement) that change the moment arm of the joint. Adequate knowledge of how the extensor moment arm is affected by tibiofemoral and patellofemoral joint mechanics is therefore essential to effective rehabilitation.

The extensor moment arm (Mact, Fig. 1) is most conveniently measured as the perpendicular distance from the patellar ligament axis to the point of tibiofemoral contact (2,4,5,6). Extensor torque is then the product of the moment arm and the patellar ligament force (Fpl). Since the force developed by the quadriceps (Fq) is not fully transmitted to the patellar ligament (1), an "effective" moment arm can be defined that expresses the actual moment arm in terms of Fq (2):

$$M_{eff} = M_{act} \frac{F_{pl}}{F_q} \qquad [1]$$

Using this definition, extensor torque is the product of the effective moment arm and the quadriceps tendon force.

METHODS

We have formulated a simple, calculationally efficient, planar knee joint model that is able to reproduce the sagittal-plane behavior of the joint. As shown in Fig. 1, the model is composed of a fixed tibia, a femoral profile with separate ellipses to approximate the patellofemoral and average tibiofemoral articulating surfaces, an idealized rectangular patella, and an inextensible patellar ligament. Contacts between structures are assumed to occur at single points without friction. The orientation and position of the femur is specified at each degree of flexion (θ) by judiciously choosing initial conditions and prescribing the pathway of the instantaneous centers of tibiofemoral joint rotation so that the movement of the tibiofemoral contact point with flexion matches that reported by Nisell *et al.* (4,5). Likewise, the quadriceps force direction (θq) is prescribed to match data provided by Van Eijden *et al.* (7). Dimensions of the model are listed in Table 1.

Starting from full extension (0 deg), the position and orientation of the

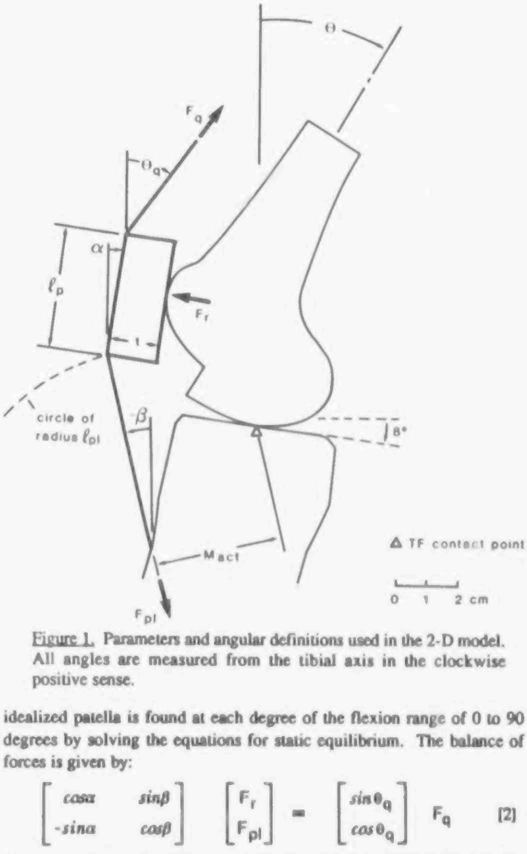

Figure 1. Parameters and angular definitions used in the 2-D model. All angles are measured from the tibial axis in the clockwise positive sense.

idealized patella is found at each degree of the flexion range of 0 to 90 degrees by solving the equations for static equilibrium. The balance of forces is given by:

$$\begin{bmatrix} \cos\alpha & \sin\beta \\ -\sin\alpha & \cos\beta \end{bmatrix} \begin{bmatrix} F_r \\ F_{pl} \end{bmatrix} = \begin{bmatrix} \sin\theta_q \\ \cos\theta_q \end{bmatrix} F_q \qquad [2]$$

where α and β represent the unknown angles measured clockwise (posteriorly) from the tibial axis to the patellar axis and patellar ligament, respectively, as shown in Fig. 1. Fr and Fpl are the unknown patellofemoral reaction (contact) force and patellar ligament tension. In addition to equation [2], Fpl must satisfy the moment equilibrium equation:

$$F_{pl} M_{pl} = F_q M_q \qquad [3]$$

where Mpl and Mq are the moment arms of the patellar ligament and quadriceps about the patellofemoral contact point (Fig. 2). Since the origin of the patellar ligament is constrained to the circle of radius ℓ_{pl} (Fig. 1), β, Mpl, and Mq are known functions of α, and equations [2] and [3] can be solved simultaneously for α, Fr, and Fpl using Newton-Raphson iteration and an initial guess of α.

Using this procedure, we found that our model agrees with observed movements of the patellofemoral contact point with knee flexion (3,5), the relative positions and orientations of the patella and patellar ligament (5,7), patellar ligament tensions and patellofemoral joint compressive forces (4, 8), and patellar ligament moment arm (4). Our curve of "effective" extensor moment arm (Meff) versus flexion angle is similar to that determined experimentally in three dimensions by Grood *et al.* (2), but differs in shape at high flexions (9). Because of the close agreement between our modeled results and the literature (10), we are confident of our ability to model and understand the basic mechanisms at work in the tibiofemoral and patellofemoral joints.

RESULTS

In addition to using the nominal parameter values (Table 1), 20% larger values of patellar thickness (t), patellar length (ℓp), and patellar ligament length (ℓpl) were run to determine the sensitivity of the curves of α, β, Fpl, Fr, Mact, and Meff, versus θ to these variations. Fig. 3 shows these curves as dashed curves, whereas the curves resulting from nominal parameter inputs are shown as solid curves. The six plots comprising the first column of the figure depict the effects of increasing patellar thickness, whereas the second and third columns show the effects of increasing patellar length and patellar ligament length, respectively. Motions of the femur with respect to the tibia were identical for the nominal and perturbed cases within each column, requiring some adjustment of the initial joint configuration to avoid hard surface violations and to obtain convergent results.

Plots A through F of Fig. 3 show the effect of increasing patellar thickness (t). As anticipated, both the actual moment arm (E) and the magnitude of the patellar ligament deflection (B) have increased throughout the flexion range since the thickness of the patella works to displace the ligament further from the tibiofemoral contact point. Note that the influence of patellar thickness on the effective moment arm is only significant (3-5%) at flexions less than 30 degrees.

When the patella is lengthened, only the portion of the patella proximal to the patellofemoral contact point is increased. This lengthens the lever arm (Mq) of the quadriceps about the patellofemoral contact. To balance this increase in torque, the force in the patellar ligament (I) increases to maintain static equilibrium. α and β also angulate more noticeably with respect to the tibial axis (G and H) at moderate to high flexion angles. The larger actual moment arm (K) and patellar ligament tension combine to yield an effective moment arm greater by nearly 14% (L) at moderate to high flexions.

Larger, but similar increases in the patellar axis orientation, patellar ligament force, patellofemoral contact force, and effective moment arm are obtained by lengthening the patellar ligament (respectively, plots M, O, P, R). Basically, these effects are qualitatively similar to those in the second column of Fig. 3, since an increase in patellar ligament length profoundly influences the moment balance (equation [3]) by simultaneously increasing the lever arm Mq while decreasing Mpl. The longer ligament increases the effective moment arm up to 27% at moderate to high flexions.

DISCUSSION

Although an increase in patellar thickness increases the moment arm of the patellar ligament (Mact), such a change alters the effective moment arm significantly only at flexions less than 30 degrees. This is because at small flexions, the quadriceps force, patellar axis, and patellar ligament are more nearly aligned than at large knee flexion angles. Hence, the quadriceps force is transmitted almost directly through the patella with a minimum of attenuation. In this case, *displacement* of the ligament away from the tibiofemoral contact point via patellar thickness is a practical means of enlarging the effective moment arm.

Table 1. Parameter values describing the model.

Description	Size (cm)
patellar thickness, t	1.63
patellar length, ℓ_p	3.94
patellar ligament length, ℓ_{pl}	6.52
semimajor radii of femoral articulating surfaces:	
femoral condyles	3.54, 2.18
intercondylar groove	2.86, 1.90

Note: Center of ellipse describing the intercondylar groove is displaced 0.82 cm anteriorly along the tibial axis from the center of the ellipse describing the femoral condyles.

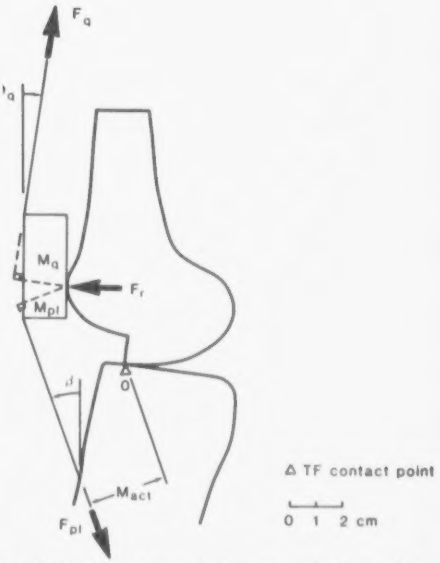

Figure 2. Initial position of the sagittal-plane knee model. Treating the tibiofemoral system as fixed, the orientation of the patellar axis (α), and the forces Fr and Fpl, are found from force and moment equilibria. Mq and Mpl are the moment arms of the quadriceps tendon and the patellar ligament, respectively, about the patellofemoral contact point.

As the knee is flexed beyond 20 degrees, the quadriceps force, patellar axis, and patellar ligament angulate strongly so that the rocking, or *levering* action of the patella about the patellofemoral contact point (reducing the tension transmitted from the quadriceps to the patellar ligament) becomes significant. Both changes to the patellar length and to the patellar ligament length affect the mechanical advantage of the patellar force lever, and thereby change the ratio of transmitted to applied force and Meff by equation [3].

Since the effective moment arm is profoundly affected by changes in patellar ligament length, we estimated upper bounds for the ligamentous strain at maximum isometric muscle force and during level walking. Our estimates of 7% and 1% strain, respectively, indicate that stretch in the ligament might be important during maximal muscle exertions, but is negligibly small for normal movements such as walking.

In summary, the effective moment arm is very sensitive to patellar ligament length and moderately sensitive to patellar length at flexions above 20 degrees. Near full extension, it is influenced to a lesser degree by patellar thickness. These studies clearly illustrate the biomechanical operation of the knee extensor mechanism, and carry implications for rehabilitative procedures in which replacement or removal of the patella is necessitated.

ACKNOWLEDGEMENTS

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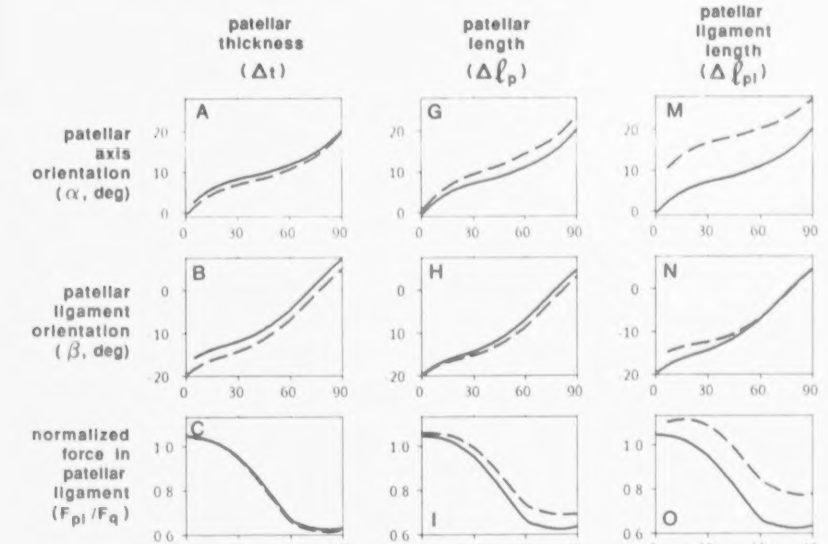

Figure 3. The effects of increasing patellar thickness (A-F), patellar length (G-L), and patellar ligament length (M-R) on knee properties calculated from the 2-D knee model. Curves corresponding to nominal parameter values are shown as solid lines, while dashed lines indicate values 20% larger.

Special Interest Group 15

Information Networking

Chair: Alexandra Enders, B.S., O.T.R.

THE STRUCTURE OF INFORMATION SERVICE DELIVERY

Alexandra Enders
Electronic Industries Foundation
Washington, D. C.

The Special Interest Group on Information/Networking has developed this special session as a forum to discuss issues relevant to the operational organization of informartion services and information dissemination in the field of disability, especially those who have an emphasis on rehabilitation technology information. We have accented community based information delivery services that target consumers. The programs all represent different perspectives, but each appears to be exemplary, and have replicable components.

SOCIETAL CONTEXT FOR INFORMATION DELIVERY

Demographers say we are getting older, futurists point to dramatic upheavals in the world of work, definitions of productivity and human value. The information we need and the ways we seek it are changing as the nature of our society is rapidly being tranformed.

In the rehabilitation field, subtle shifts have been occurring due to the Independent Living/Disability Rights Movement, and it is obvious that new approaches must soon be considered in the way information needs are defined and met as individuals with disabilities prepare to meet the challenges of our changing times.

THE IMPACT OF TECHNOLOGY

Technological advances have played an important role in the exponential rates of change. The "information age" would be impossible without it. It has structured both need and demand; and provides us with mechanisms to address these issues.

Newer technologies, especially new software, will facilitate collecting, storing and transferring the right information, to the right people, in the most appropriate format, when and where they need it; it will allow easier and cheaper access and updating. It is possible now to have information bases which have different entry points for individuals with varying levels of expertise. New technology allows the information needs of the user to determine the format and content of the database rather than the hardware/software determining it; and enables compatibility not just between hardware and systems, but also among networks of cooperating information service providers. Information distribution is about to enter a new era.

THE INFORMATION BUSINESS

Conceptually it has sometimes been difficult for people in the human services field to see themselves as being in "business". However, new trends have created the information business, and if you are providing information services, whether you like it or not, you are in that business.

There are a great number of underlying issues which must be addressed and questions to be answered as we plan for the changing nature of information seeking strategies. This forum will be a starting point for continued discussion on topical issues of mutual concern.

OPERATING AN INFORMATION SERVICE

Operating an information service or a network requires the integration of sound business principles. Program planning and development, marketing strategies and resources development are vital aspects to any operation that intends to stay in business. Drawing on the experiences of several exemplary rehabilitation information service delivery programs, strategies will be discussed for value and replicablity. The promise and pitfalls of different community oriented services are described, and suggestions offered on ways to improve operations and services.

INTEGRATING INFORMATION STRATEGIES

The outcome of our information service activity must be its impact on the lives of disabled people. While there is a new awareness and emphasis on providing information directly to individuals with disabilities, it is also apparent that the specific information needs of other segments of the rehabilitation field - research, manufacturing, service delivery, clinical practice, education, can each be quite different than the knowledge sought by the average disabled consumer. A strategy for acheiving integration is offered, which helps us to learn from the experience of other fields in integrating information management.

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SENSORY TECHNOLOGY INFORMATION SERVICE

James A. Whitlock, Jr., MD, President and Executive Director
Ellen A. Trencher, Project Coordinator
New England Institute of Sensory Science

ABSTRACT

The New England Institute of Sensory Science (N.E.I.S.S.) is an independent, non-profit organization of clinicians and other professionals. Our group develops and demonstrates solutions to problems of major sensory (hearing, vision, touch) disability. A major commitment has been to the design and development of model service programs. Our major project, the Sensory Technology Information Service (S.T.I.S.) offers persons with sensory disability information on currently available assistive technology and special services. A N.E.I.S.S.-based computer database is at the core of our operation. Inquiries are welcome from all over the country. The information is provided at no cost to the sensory-impaired and available in a variety of formats to accomodate the special needs or preferences of the disabled.

INTRODUCTION

S.T.I.S. is designed to answer questions about what, which and how available devices and services can lessen the disability of a major sensory loss; questions about what products exist AND are available, what various devices can and cannot do, how much they cost, and how people have used them. We can tell someone which products have become unavailable over recent years. We provide concise, specific descriptions about any product related to the inquirer's question. An N.E.I.S.S. based computer database serves as an important tool in answering service user's questions, but it is only one of the resources used by S.T.I.S. staff to provide the best answer possible. Other resources include N.E.I.S.S. consultants, (including disabled consumers), literature, vendor contacts, and other databases.

The service provides direct service to residents of New York, New Jersey and the New England states (through a toll-free number made available in May 1986). Users within Massachusetts can call collect. Within the last year, requests have also been accepted from other areas of the country. Reports are available in standard or large print, over the phone, via TDD (Telephone Device for the Deaf), on cassette and in Braille. The service is without fee to sensory-disabled; organizations or non-disabled are charged nominal fees based upon time spent fulfilling the request.

BACKGROUND

There is a vast array of aids, devices and high-technology available for use by persons with disabling degrees of hearing or vision loss. Because of the small-business nature of many of the marketing companies and the wide geographic distribution of consumers, many persons who could benefit from the technology never learn of its existence. Because of the tremendous flux in a rapidly evolving electronics industry, many products have been superseded by low cost, sometimes higher-quality products. This flux has also affected the existence of some of the smaller producers of sensory aids.

The combined result of all these factors is constantly changing information on products, their availability, and their pricing. Furthermore, what information IS available (eg. from vendors, libraries, 'information and referral agencies') is generally provided in standard print or within the context of a publication. The very nature of sensory disability is such that special media (Telephone Device for the Deaf, large-print, cassette, Braille) are required to communicate complex information effectively. S.T.I.S. was initiated as an attempt to deal with each of these issues in a new, effective way.

S.T.I.S. began operations in January of 1985. Funding for the first two years has come from the Stoddard Charitable Trust, the George and Sybil Fuller Foundation and Memorial Homes for the Blind. Donations-in-kind were received from IBM, Multimate International and Ashton-Tate (1985) and from the Institute for Scientific Information in 1986. The first year of the project was primarily spent purchasing the necessary equipment and setting up the database. Initial database entries came from the ABLEdata database of the National Rehabilitation Information Center at the Catholic University of America.

This past year, significant efforts were directed at designing and implementing a public-information program to let organizations and the general public in our region know of our service. Efforts concentrated on press releases and direct mailings to educators, social service agencies and organizations that work for or with the sensory disabled, as well as some paid advertising. It subsequently became obvious that major efforts in public information would have to concentrate on reaching the sensory-disabled as directly as possible on a recurring basis. S.T.I.S. will reach its full potential only if its nature and existence are widely known by the sensory-disabled or their families and friends. A major thrust of the coming year will be a public relations campaign through articles and paid advertising in specialty magazines and regional newspapers. Attempts will also be made to secure free public service slots at selected radio and television stations throughout New England and New York.

The Sensory Technology Information Service is designed to be a nucleus for an assortment of 'special projects' involving study of topics related to technology and services for the sensory-disabled. To this end, the following activities are underway:

1. Establishment of a database on unique services for sensory-disabled in this country (i.e.-those not widely available or those available only to individuals meeting special criteria: Cochlear implant programs, tactile art exhibitions, 'bubble' hearing aids, Braille printing centers, unique educational or vocational programs);
2. Addition of experimental products to the master S.T.I.S. database along with relevant literature citations;
3. Establishment of a database on sensory-diagnostic apparatus with a focus on unusual and low-end practical aids to the clinical assessment of sensory loss.

Another component of the S.T.I.S. program was to involve the evaluation of new or existing (but not formally evaluated) devices for the sensory disabled. Although present budgetary and personnel limitations preclude the sort of technology evaluation program that is needed, N.E.I.S.S. is gathering consumer-based evaluation data on an assortment of hearing-related technology. As flaws in operation or design of equipment used by N.E.I.S.S. (in any of its programs) are identified, manufacturers will be notified and specific improvements suggested.

A major goal for the coming year is to become less dependent on grants and donations by expanding our contractual services through marketing to organizations, vendors and other databases. Ultimately, we hope to incorporate S.T.I.S. into a specialized library that will be one component of an independent sensory research and technology center. Expandible sources of project revenue include the following:

1. Sale of database information on IBM compatible diskettes;
2. Periodic publication of hard copy versions of our database;
3. Sale of database information to other information services and databases;
4. Sale of on-line searches on rehabilitation technology outside the field of sensory disability;
5. Sale of Computer text-Braille transcription with extra fees for key-input or graphics;

There are several major questions related to access, use and 'usefulness' of sensory technology that are begging to be answered- and which should be answered by independent organizations committed to the removal of barriers between sensory-disabled and the educational, vocational and general living opportunities that all people deserve. What potentially important assistive devices produced in other countries but not generally available in the U.S. might be purchased by U.S. consumers/vendors? Can useful guidelines on 'appropriate technology' be created for people/organizations with extremely limited resources or unique cultural/environmental-circumstances?

What problems do consumers experience with existing technology? Why? What can be done to resolve these problems? Where do individuals secure funds to purchase the devices, if they cannot afford to do so themselves? What assistance, if any, can be obtained from state and federal agencies; from clubs, foundations and private agencies?

The Institute would like to be able to answer each of the above questions through S.T.I.S. Special funding, support staff (research and clerical assistants), and additional consultants from clinical fields, engineering, special education, and social services are required to answer the questions properly. Recruitment and training of skilled volunteers to act as research assistants, consultants in special areas of sensory technology and general office help will continue to assist in progress toward goals of S.T.I.S. Paid staffing will remain central to the success of the project, including the effective use of volunteers.

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INFORMATION SERVICE DELIVERY FOR PHYSICALLY DISABLED PEOPLE

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ABSTRACT

This presentation discusses the various components pertinent to the development of a comprehensive Aids and Devices Display Centre and Information Service established to meet the information needs of disabled people, their families, rehabilitation professionals, health care workers and organizations. Using the model of the Disabled Living Resource Centre at the Kinsmen Rehabilitation Foundation of British Columbia, Canada, reference will be made to program planning and development, resource development and marketing strategies.

INTRODUCTION

Prior to the 1980's, disabled people searching for answers to problems associated with a physical disability had little access to information. Passed on from one group or agency to another, receiving only partial answers at each step, they usually gave up in frustration. The need for a centralized comprehensive information service was apparent. This need had been well documented in publications by a number of national organizations as well as my own provincial organization, the Kinsmen Rehabilitation Foundation of British Columbia (KRF).

BACKGROUND

The Kinsmen Rehabilitation Foundation (KRF) of British Columbia is a non-profit organization providing services to physically disabled people of British Columbia. It is almost totally funded via our own fund raising efforts, with less than 5% of revenues coming from government. British Columbia has a population of approximately 2,500,000 people, half of whom live within a 50 mile radius of Vancouver. Access to information, particularly in rural areas, was very difficult and presented some unique problems. Therefore, an organization such as the Kinsmen Rehabilitation Foundation with associated Kinsmen Clubs (77) throughout the province would have advantages in assimilating and disseminating information on a provincial and perhaps national scale.

In 1973 at a conference in Victoria, British Columbia, the "Disabled Living Resource Service" proposal was presented by the KRF as part of the "Report of the Advisory Committee on the Needs of the Physically Handicapped". The proposed "Resource Service" was modelled after the Disabled Living Foundation in London, England, which had been established in 1970.

It was not until 1979, however, that the KRF was in a position to further develop the proposal and generate enough revenue to initiate the proposed display centre and information service, The Disabled Living Resource Centre (DLRC), a first and still the only Centre of its kind in Canada.

Program planning and development

With a goal of opening the Disabled Living Resource Centre for the International Year of Disabled Persons, a graduate student in Health Services Planning at the University of B. C. was hired along with myself (who was already on KRF staff) to prepare a plan for implementation of the original proposal. The final plan encompassed the following objectives:

1) to establish a continuing comprehensive program of direct assistance to handicapped people and their families by furthering greater independence through the collection and distribution of knowledge of available facilities, services and equipment;

2) to establish an Aids Display Centre to acquaint disabled persons and professionals alike with the latest available in aids and equipment;

3) to provide facilities for seminars and educational programs where information can be shared.

By the fall of 1980, the KRF headquarters building had undergone major renovations. Approximately 2,000 square feet of space had been allocated to accommodate the DLRC which would include an aids display, library and office. Operational procedures were finalized and staffing requirements were filled: a manager, a librarian, and a secretary. The DLRC was officially opened on October 4, 1980. Just over a year ago, a library technician was added to our staff complement. We have also been fortunate in employing students via Canada Summer Employment projects plus the help of regular part-time volunteers.

Resource Development

Aids and equipment display. To furnish our display area, it was decided to aproach suppliers/manufacturers to supply equipment and devices 'on loan' to the

DLRC for a designated period of time. This we did and have not met with any resistance or problems to date. Indeed quite the contrary! The DLRC has proven to be an excellent showcase for their products. All items on loan are covered by KRF insurance and we assume responsibility for them while on our premises. I must emphasize that we do not assess, recommend or sell any items. Our role is to inform the enquirer what is available, where it is available and if possible, the approximate cost. This practice may in part contribute to the success of the DLRC as the client does not feel pressurized in any way when visiting us.

The display area now occupies approximately 1,500 square feet and exhibits more than 400 aids from 55 suppliers/manufacturers in a comfortable, non-clinical, homey atmosphere. It features bedroom, bathroom, kitchen and living room aids plus a mobility area and a section showing a wide range of communication aids and other sophisticated electronic equipment.

Information service and library. The information service and library of the DLRC started in a small way by collecting our own 'in-house' data and publications and storing the information on a card index system. It was evident that this method had many shortcomings for the future. Our librarian studied a number of other systems currently in use: NARIC, ABLEDATA, Nordic Information System on Technical Aids, CRCD Keywords, etc. and decided that a comprehensive system combining elements of the other systems was needed. After months of work, with the help of computer consultants, our librarian devised a new information classification and retrieval system called KRIS (Kinsmen Rehabilitation Information System) which would meet the needs of disabled people, families, rehabilitation professionals and students.

At the same time as KRIS was being developed, the KRF was investigating the need to automate the Foundation's office and administrative procedures. This resulted in the installation of a WANG OIS word processing system. KRIS was soon incorporated onto the WANG. We have since acquired and transferred over to the WANG 2200 mini-computer and added a telecommunication link.

KRIS is composed of Subject Descriptors Classification Scheme and a Classification Index containing approximately 2,000 index terms. The databank contains over 5,000 records pertaining to publications, equipment services as well as a directory of manufacturers, service organizations and publishers.

There has been a great deal of interest in KRIS both nationally and internationally. It has been purchased for use in Australia and New Zealand as well as in other parts of Canada.

From very small beginnings, our research lending library has also grown like topsy. Our holdings include over 1,200 brochures/pamphlets on equipment and service organizations; 90 equipment catalogues; 2,000 books; 175 periodicals and newsletters; 40 films, tapes and audiovisuals; 15 multi-media kits (braille large print, etc.) and cover a wide range of topics such as travel, access guides, housing, cooking, legislation, attitudes and communication aids to name a few.

We receive, process and/or update approximately 10 - 15 pieces of new information per day to maintain the accuracy and currency of our KRIS databank.

Public education. An important and vital component of the DLRC, from the beginning, has been our public education emphasis. The staff of the DLRC are not only trained information providers but very competent equipment demonstrators and tour guides. We offer conducted tours of the DLRC to disabled persons and their families, homemakers, occupational therapists, volunteer groups and the general public. We have become an educational facility not only for students of rehabilitation, special education, nursing and bio-medical electronics from community colleges, but also to young school students, boy scouts and girl guides.

Occasionally, we are fortunate enough to obtain the services of experts who volunteer their time and expertise to present special interest workshops such as gardening or personal grooming for disabled people.

Marketing Strategies

When one is launching a new product or service it is absolutely vital to use all existing media resources and even invent some of your own to 'tell the people'.

Perhaps our major awareness project (marketing thrust) in 1981 was the Disabled Living Resource Centre Mobile display unit. A sixty foot trailer was specifically built and equipped with all the necessary utilities: heating, air-conditioning, special lighting, radio telephone and front and rear door wheelchair lifts. The logistics of moving this unit throughout the province was a task in itself, however, we felt that the whole project was extremely worthwhile. The Mobile was outfitted like a mini-Resource Centre complete with display equipment and a small library. For six months the Mobile plus two staff travelled to all the major cities and towns in B. C. including some very remote locations. In all, fifty-five communities were visited and thousands of people visited the unit. For some people, it was the first time they had ever been exposed to rehabilitation and independent living equipment or a source of rehabilitation information.

A thirty-minute television program, funded by our provincial government, was also produced. It was and still is shown on community television stations and educational networks. At the request of media people and at no cost to us, we have been the subject of written articles plus numerous special interest TV and radio programs.

We have produced several slide presentations for community and organizational awareness plus mounting displays at shopping malls, health fairs, conferences and various events that focus on information and awareness services for specific groups and/or the general public.

The KRF publishes 'Image', our own quarterly newspaper with a readership of approximately 60,000. Each issue contains a four page DLRC Information Bulletin insert focused on a particular topic of interest, ie. kitchens, mobility, post polio syndrome, or perhaps gardening. We have been told that these bulletins provide a valuable reference source and many people collect each issue.

Through our affiliation with the Canadian Rehabilitation Council for the Disabled and the Kinsmen Clubs of Canada, in particular our B. C. Kinsmen, we enjoy an excellent organizational network and the opportunity to gather and disseminate information on a local, national and international scale. Our leadership role in organizing and producing the EXPO '86 Specialized Period for Elderly and Disabled People was an example of cooperation and organization on a major scale. It brought exhibits of wonderful new technology and awareness to the attention of thousands of people from all over the world who visited EXPO '86.

CONCLUSION

Our plans for the future include a provincial computer network serving disabled people/organizations and the participation in a national network of similar resource centres. Several are on the threshold of opening and we look forward to this linkage.

To assist disabled people in their quest to be well informed and as independent as possible in our rapidly changing society is indeed a challenge. There is no doubt in my mind that information resources are playing a major role in this quest for independence. The DLRC is a fair testimonial!

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LINKAGE: A CONCEPTUAL VIEW OF INFORMATION DELIVERY IN THE REHABILITATION FIELD

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One view of independent living is that a person lives independently when, and if, they are making the decisions that produce outcomes in their lives. Since information is needed for decision-making, it follows that barriers to information delivery are barriers to independent living. The rehabilitation field is beginning to reduce barriers to information delivery but what could be called an integrated strategy has yet to emerge.

An integrated strategy for information delivery is defined as one which efficiently links senders and receivers of information. The starting point for linking senders and receivers in the rehabilitation field should, arguably, be the receivers of information (disabled individuals). This paper develops the argument for a receiver-first linkage strategy.

BACKGROUND

Information delivery is a term that is used to refer to the variety of processes by which individuals, or groups, are informed. Information delivery processes link senders and receivers of information. Information delivery processes vary in terms of who says what to whom; by what channel; to what effect; and for what purpose, (i.e., which sender sends what message to which receiver for what purpose and to what effect). Information delivery processes also vary in terms of how efficiently messages are sent between senders and receivers, and in terms of how efficiently these messages are used to organize effort in a particular field of activity. In general, efficient information delivery processes mean 1) that receivers of information are better informed and 2) that the better informed receiver is more efficient, in economic terms, within a particular field of activity (Machlup, 1982).

INFORMATION DELIVERY AND UNMET NEEDS

We can think of senders of information as producers of goods in a marketplace and receivers as their customers. If the marketplace is efficient, producers will ship more goods and, as a result, the standard-of-living of their customers will rise. We are accustomed to measuring the efficiency of a field of activity in economic terms (e.g. units of product shipped and standards-of-living), but not accustomed to measuring a field of activity in terms of information delivery processes. However, any economic measure of the efficiency of a field of activity is actually an indirect measure of the information delivery processes operating within that field because market transactions depend upon information delivery. There are times when describing a field of activity in terms of information delivery is more explanative than describing it in economic, demographic or statistical terms.

For example, the National Center for Health Statistics has estimated that 3.5 million Americans use assistive equipment or the aid of another person to perform basic personal care functions. No estimate is available on the level of unmet needs that exists for assistive equipment. However, despite the fact that the level of unmet needs cannot be specified, the phenomenon can be explained, in part, in information delivery terms. Scadden (1987), for instance, has reported that people's unmet needs for assistive devices can be traced to the fact that manufacturers have difficulty locating the disabled directly and, therefore, must deliver product information through professional prescribers.

Scadden notes that in this instance normally beneficial privacy act legislation has a downside. Manufacturers cannot get access to patient lists to identify people who need to know about their products. Hence, senders (manufacturers) and receivers (disabled individuals) can only be linked through professional prescribers. There are economic and social costs associated with the privacy act legislation. Manufacturers ship fewer products and the standard-of-living of disabled people with unmet needs falls as a result of this policy barrier to information delivery.

One remedy would be to remove the privacy act barrier -- to authorize patient lists to be sold to manufacturers. This remedy is not offered as a policy recommendation, but as an example of a sender-first strategy for removing barriers to information delivery. This is a sender-first or "supply side" strategy because it empowers the sender of information to disseminate more information, more efficiently and to greater effect, but it says little about the receiver. This strategy does not empower the intended receiver in any explicit way. It is merely assumed that this sender-first strategy will have an intended effect on the receiver. It is assumed that the receiver will be better informed and that his, or her, standard-of-living will be raised as a result of implementing the strategy.

SENDER VERSUS RECEIVER-FIRST STRATEGIES

Sender-first strategies for improving information delivery are far more common than receiver-first strategies. There are, at least, two reasons for this. Sender-first strategies for improving information delivery tend to involve computers and information handling services. Strassman has estimated (1985) that 67% of the wages currently paid to American workers are paid for information handling services (rather than for the production of tangible goods) and that 70% of the labor hours in the U.S. economy in 1982 were spent on information work. In 1982, 33.4% of the nation's capital investment went toward computer equipment. By 1990, it is estimated that the nation's information systems budget will be $600 to $650 billion dollars, or 10% of gross national product. Clearly, one of the most explosive investment booms in history is underway and it is aimed at equipping the senders of information. Since two thirds of the workforce is already employed as information workers (senders), it becomes clear why sender-first strategies tend to come to mind when information delivery barriers in any field are encountered.

A second reason why sender-first strategies predominate is that the information-seeking behavior of receivers of information is just not well understood (Lancaster, 1979). In contrast to the large literature on how humans learn, much less is known about what motivates receivers to seek information; what effect information has on the personal strategies and perceptions of receivers and how much, and what kind of information receivers need. Lack of knowledge about the information-seeking behavior of receivers does not deter us from making unquestioned assumptions about that behavior. In the U.S., it is commonly assumed that if an information delivery barrier arises, senders need to invest in information systems (Strassman, 1985). It also tends to be assumed that if these investments are made, receivers will be motivated to acquire and use moreinformation and will be made more efficient (by extension) by the sender's investment in information delivery systems. Actually, it is more likely that in Japan receivers would benefit directly from investments in information delivery systems made by senders. That is because the Japanese culture reveres information-seeking behavior by individuals. In the U.S., however, the casual information-seeking behavior of the modal receiver is more likely to serve as a disincentive, or even a barrier, to information delivery despite our assumptions to the contrary.

Of interest is the role of the individual member of a disability group as receiver. An important view of independent living is that a person lives independently when, and if, they are making the decisions that produce outcomes in their lives (Zola, 1982). Since information is needed for personal decision-making, it follows that barriers to information delivery are barriers to independent living for the disabled. How much of a barrier to information delivery (and by extension) to independent living, is the disabled receiver's own information-seeking behavior? No one can say precisely. It is a question not much asked because 1) too little is known about the information-seeking behavior of the disabled to even pose the question well, and 2) it is more conventional to ask about senders and how they might disseminate information more effectively.

THE STARTING POINT FOR AN INTEGRATED STRATEGY

An integrated strategy for information delivery is one that considers the joint outcomes of sender and receiver-first strategies and blends the two to produce the optimal level of economic efficiency (i.e., the highest standard-of-living for the disabled individual). Perhaps receiver-first strategies are the logical starting point for an integrated strategy for the rehabilitation field simply because sender-first strategies are so more likely to be undertaken, and; because the potential impact of receiver-first strategies is unknown, yet conceivably, large.

Any receiver-first strategy for the rehabilitation field must take the disabled receiver's information-seeking behavior into account. The constituents of this behavior are the following: 1) the receiver's goals, 2) the task structure, 3) the knowledge available to the receiver and 4) the receiver's processing limits. The receiver's goals (1), refer to the ultimate aim he, or she, has for the information. The more prized the goal, the more intensive the information search. The task structure (2), refers to the framework in which the information-seeking task is embedded -- is the information task the result of a school assignment, part of a job search? Is it easy, or difficult, to master the information task? The knowledge available to the receiver (3), refers to the amount of information that the receiver already holds on this, or related, topics. In general, the more knowledgeable the individual already is, the more effort that he will expend to acquire the next marginal increment of information on the topic. Finally, (4), the receiver's processing limits refers to the physical and/or cognitive limitations on information-seeking that may be imposed by the receiver's disability.

A receiver-first strategy being tested by SwRI's REC is to entrain the interest of disabled individuals in evaluating their personal coping strategies. Sharing these evaluations of personal coping strategies is promoted by an electronic bulletin board that permits members of disability groups to participate jointly. Scoring procedures are being tested which make the comparison of seemingly incommensurable attributes more meaningful to members of groups that are sharing data on evaluation. Work with groups of retired, chronic vascular disease patients, and severely involved cerebral palsy young adults is currently underway. With the vascular disease cohort (40 members), participants are being asked to evaluate a taxonomy of personal strategies that they employ in coping with their heart disease. The results are being compared with their progress in reducing serum cholesterol, managing hypertension, losing weight and modifying other risk factors.

In the cerebral palsy cohort (16 members), participants are practicing decision-making and evaluation skills in a four stage process that will culminate in their full participation in the design of their new residential facility. The design alternatives will be functionally decomposed and computerized such that the participants can vote, consider trade-offs, request extra information, and/or caucus with others to consider these issues in more depth . A question for research is whether these evaluation procedures encourage information-seeking behavior. It is clear that questions arise during the course of in-depth evaluations on matters of serious personal concern like one's disease course, or future residence. The structured, ongoing interaction with others may also, ultimately promote information-seeking behavior by participants. If so, a next step would be to use the same electronic network that is used to structure the evaluation exercises as an information delivery system. This, in theory, would represent an integrated strategy for information delivery. In this model, the demand for information is promoted within groups of disabled individuals that share demographic attributes, have a common, serious purpose for interaction and benefit from the evaluations they participate within. This is a receiver-first strategy. How to interface the supply side information delivery system to these evaluation networks are secondary considerations in this view.

CONCLUSION

Information delivery is critical to the enhancement of living standards among the disabled and to producing independent living outcomes. The efficiency of information delivery in the rehabilitation field is clearly dependent upon developing, and maintaining, certain sender-first strategies that emphasize bibliographic data bases, electronic networks and other computer and information services.

However, to take full advantage of information delivery channels in the rehabilitation field, the supply side (sender-first) strategies should be pulled by demand side (receiver-first) strategies that take the personal information-seeking behaviors of disabled individuals into account. Research is needed on incentives that encourage, and enable, disabled individuals to participate in evaluative and information-seeking activities. Research is also needed on information delivery barriers that arise as the specific result of the information-seeking behavior of individuals.

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STARTING AN INFORMATION SERVICE: ISSUES AND QUESTIONS

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ABSTRACT

Many important issues complicate the development of an information service and these issues raise questions that should be asked before an information program is started. This paper discusses these general issues and questions to assist in planning new programs.

INTRODUCTION

Many rehabilitation and independent living programs are starting in-house information services. These new programs succeed in direct relation to their ability to manage information. However, the increasing volume of information in the rehabilitation field makes it difficult for each staff member to keep up-to-date.

Frequently, information services are designed around one specific need and have to add components or features as new needs arise. Information managers reluctantly admit that this sometimes requires reorganization of the entire program to retrofit the new process. To avoid constant upheaval or continuous reorganization, programs should be designed to be flexible so that they can change smoothly when user and other needs require it.

The following is a compilation of questions and issues to be answered or defined when designing an information service. Some of the questions are easy to answer. The others are really issues that are critical to the overall design of the service and require policy decisions--or possibly compromises--on exactly what services will be provided.

DISCUSSION

The first set of questions seems obvious but often is overlooked in the enthusiasm of getting an information service up and running. First of all, have you defined the information needs of potential users as completely as possible? Then, have you completely defined all your resources, e.g., financial, space, personnel, experience, marketing capability, etc.? If the available resources are not sufficient for the needs, have you prioritized the needs or goals? Have you identified the goals that can be attained with the available resources? Have you written policies outlining the scope of the program according to the defined needs and available resources? Written policies help to keep staff on-track when they are making independent decisions on whether to include certain information in the database, and policies also help the staff to respond effectively to specific information requests.

The second group of questions concerns what type of information will be provided and how it will be managed. First, what kind of information is to be included in the information service? How will it be administratively managed? Will searches be provided from public databases? Will there be charges for the service? If so, have policies for invoicing and fee collection been defined? Can organizations set up deposit accounts with the service? If you have received a grant to start the information service and do not have to charge for services in the beginning, how will the program be supported after the initial funding runs out? If income from fees will be needed in the future, should you start charging a minimal fee in the beginning? Will fees deter people from using the service? Often a minimal fee will encourage users to make more realistic requests, instead of general "everything you have" requests, and will preserve the sanity of the information providers.

The next set of questions deals with the configuration of the information system. How will you decide when to use manual or computer-based systems? What is the volume and the complexity of the information you will be handling? For simple referrals, a rolodex can be just as efficient (and sometimes easier) than a computer. If you have complex files with double and triple cross references, a computerized system will simplify the process and take the place of additional staff by allowing requests to be answered more efficiently.

If you decide to use a computer, the next questions are about the software and hardware you will select. Which software package do you need and which computer system supports it? Specifically, how much memory is needed in the computer? Will only floppy disks be used or is a hard disk needed, and if so, what capacity should it have? These decisions may be forced by the software chosen. Careful attention needs to be paid to the selection of the software since it will dictate what and how much information can be stored and retrieved. Does the software fit the space needs of individual documents? Many data management programs have limitations on the length of each field (paragraph) and the number of fields. How much data do you anticipate needing to store? When you have made your software decision, it is easy to verify that the memory and disk capacity meets the space needs for all your programs, storage, and backup files. Is it important that your system be compatible with another system? Does your software allow you to download from online databases and print the information later? This is cost-efficient because you pay only for the data retrieval which is done at a faster rate than the printing.

After you have selected the computer software and hardware and have keyed data into the system, you may think that all the problems and decisions are behind you and that only the fun part of answering requests lies ahead. Wrong.

Now you have to think about training the staff. While the people who designed the system are still on staff, training is not a critical issue. But, as staff turnover occurs, how do you choose the best information staff? What are the best credentials for the staff members who are responsbile for entering, retrieving, and searching the data for the ultimate purpose of fulfilling users' requests? What are the minimal acceptable credentials, and should there be different levels of positions? What is the training process for new information staff? It is rare to find someone who can start to work in a specialized information service without a long training period.

If you decide that staff members should perform different functions, the following policy issues must be addressed. How do you decide who will do what? All staff members should learn the in-house system, but should they all learn to search the public databases that charge hourly online fees? The more a person searches a database, the more knowledgeable and faster that person becomes. With this in mind, should one person be assigned to do all public database searches to ensure the most cost-effective use of time and money? When is it more effective to use a professional searcher for public databases?

What will determine the limits of a response to a request? Specifically, how much information should your staff provide in response to a request, whether searching the in-house or the public database? When do you keep searching and at what point do you quit? This needs to be answered whether there is a huge amount of information available or very little. Will the answer to this question be different for different kinds of users or requests? To answer this, another policy decision must be made.

How do you keep the information in your files up-to-date? Do you verify the accuracy of the information in the files? What quality control measures will be used to ensure the accuracy and completeness of the information that the staff enters in the in-house database and on the responses to information requests?

It's very easy to become overwhelmed by trying to do too much in an information service. To avoid this, have you set up information-sharing systems with other centers? Are you involved in networking or do you know how to create linkages to develop networks? When help is needed to answer a question, hours of work can be saved by calling other services in the network. Will you refer users to other centers when appropriate? In some instances, a referral to a specialized program is the best answer.

A final and very important issue is, selling the service. When will you start? Selling is an essential component to any program and needs to be timed correctly. It can't wait until all the information components are completed and the staff is ready for users to call or come in the door. Conversely, you do not want to actively sell a program that does not exist. Who should sell the program? Should you get professional help to develop a market entry plan or to do graphics for a brochure or other materials? Where will you sell your program and how hard should you push it? To balance sales and fulfillment, you must determine how many information requests the staff can handle at one time. Floods and droughts of requests can be frustrating and can make it difficult to plan effectively.

These are the important issues that surface when setting up an information program. Finding the answers to them may raise other, unforeseen issues, whether you are trying to replicate a simple referral service or a more sophisticated one. Fortunately, there are many centers in the United States that are willing to share their experiences and help others plan their information services and avoid the trial and error approach.

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TRENDS INFLUENCING REHABILITATION INFORMATION DEVELOPMENT AND DELIVERY

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ABSTRACT

Demographic changes, societal trends and technological advances are redefining the information environment, the perceived need for information, and the ways information is developed and distributed. The importance of being able to place rehabilitation information into a broader context both chronologically and demographically cannot be underestimated, although it is often overlooked. Information is (or should be) applications oriented; and applications depend on one's view of the needs to be addressed. The underlying question that must guide our future planning is: How can people with disabilities equitably get the services, products and information they need to be fully participating members of society? Without addressing this larger perspective, developing new databases and electronic delivery systems can have little intrinsic meaning.

REFOCUSING: TOWARD THE GRASSROOTS

The Independent Living/Disabilty Rights Movement is having a profound impact on the field of rehabilitation. Though the changes may be subtle, and often not yet apparent, issues of selfdetermination echo a recurrent theme. The 1986 Harris Survey documents an increased self perception of disabled people as a minority group. There is no turning back as a self help initiative develops into a civil rights paradigm; especially when the issues it addresses are such an integral part of the "long term care" dilemma we are facing as a nation. With the shifts that are occurring, it is obvious that new approaches must soon be considered in the way needs are defined and met.

The traditional view of delivering information to disabled people usually involves a ripple effect, with the professional targeted at the center. We have believed that if we can get the info-mation to the professionals and their educators, it will somehow reach disabled individuals. For some percentages of disabled people, and in some settings, that works. Community based experiences however, show me that most people with disabilities have little, if any, contact with the professionals who have the right information; and if you doubt that in the traditionally defined disabilities, just consider the growing number of older people who could benefit from practical rehab related information, and are not getting it. Most disabled people aren't sick, and may not have been in a rehab setting for years, if ever. Some disabilities like arthritis just creep up; and most people still don't want to be stigmatized by the label "disabled".

Even if this perception that most disabled people incorrect, a strong case can still be made for increased emphasis on a grass roots information system: it fits with the expanding self-help trends in all areas of everybody's life. This approach also reflects the recommendations of the National Council of the Handicapped in its 1986 Report to the President and to the Congress of the United States, Toward Independence, that stresses increased emphasis of initiatives for equal opportunity, independence, prevention, and self-sufficiency.

AN EQUITABLE PUBLIC POLICY

Disability related public policy must be developed that addresses the rapidly changing information environment of modern life. Information has been equated with power in our "Information Society". If citizens with disabilities are to equitably participate, the underlying issues related to information access must be identified, addressed and planned for.

THE INFORMATION ENVIRONMENT IN TRANSITION

Our world is changing; the first place to go for information now may be the on line database, then move on to the hard copy it guides you to. It is actually cheaper to do a literature search on most databases than it is to do it by hand. A study by Stanley Elman showed that the average cost for an online search with DIALOG is $47, while the average cost for the same hard copy search when library staff time is factored in is $250.

This may be everyday reality to us, but, is this the world most folks live in? Is this the world most disabled or aging individuals live in? Working in a high tech supported environment it is easy to get swept along in the daily excitement of emerging developments. Revisiting the disability community in Berkeley, or a grandmother in a small town nursing home, can seem like a foray into an underdeveloped country! No one there is considering the difference between $250 and $47 for a database search. They are still asking for a catalog on aids, if they are sophisticated and have been through rehabilitation; or "what's a low vision aid?", if they weren't.

When there are such obvious needs, and yet such large discrepancies between what could exist and what does exist, it is hard to continue to work at systematically developing information services one piece at a time. It must be recognized that it may take years until a friendly, solution oriented information system is available to disabled people at the grassroots level. Yet if we insist that the entire system be developed at once, nothing is likely to happen. Developmentally, we probably have not quite reached a point of knowledge where we can load the entire structure of any ideal information system we could plan.

Economic resources are a critical factor for a developing information system. There are inherent and predictable problems with trying to make any one component financially self-supporting, when the rest of the pieces in the system are still missing, and people are, therefore, not able to get the total package of information they need. It is, for example, unrealistic to fault the ABLE database for not providing information on local service providers or adaptive techniques; or for not matching needs to solutions, when that segment of the system was not designed or intended to provide those other types of information; and the ancillary data sources have not yet been organized in a complementary fashion.

I would like to hear more complaints that there is no one to interpret the available data into information meaningful at the community level, rather than complaints about a passive database and its inability to deliver what I need. There is a real need for a community based "interpreter" who can facilitate the flow of information both up and down the channels. Databases or information systems alone cannot do the task in this transitional era. And some people believe that machines, no matter how expert, will never be able to perform this task adequately.

ATTITUDE SHIFTS AND THE RIGHT TO ACCESS

In order to say what we want the answers to look like, we must know what people are really asking for. Careful analysis must be done in this transitional period. What people say they need and want, and what they are ready and able to use, and willing to pay for, are during paradigm shifts often quite different. Disabled people must be involved with planning and implementing a system - that is part of the I.L. paradigm; and, from that perspective, only common sense. Part of the effort needed to move information activities into an I.L. paradigm will be to help disabled people shift their thinking about their right to access to a wide range of information. Currently, medical and rehabilitation professionals are functioning as the gate keepers for much information that could be disseminated through libraries, ILP's, and other public sources. Attitude shifts must accompany hardware/software changes and access points.

Elizabeth Pan is all too correct when she says that we really don't know much about the information seeking habits of disabled people. But then again, perhaps we do know what these information seeking habits are - they are our information seeking habits. Ask yourself how you'd find information if you weren't in this field. Or better yet, ask your grandmother.

TOWARD AN IDEAL SYSTEM

For a moment, try to forget that we are looking at a disability/rehabilitation focused population. Within the foreseeable future we are all going to have access to electronic knowledge bases that will help address the problems of everyday life... from figuring out how to deal with the bugs on the roses, to removing stains from the carpet; from meal planning and preparation, to getting the highest performance from your car, to what to do with you leisure time.

These systems may or may not have human "interpreters", but any good information system for finding solutions to the routine problems of everyday life would encourage you to explain your problem in simple terms, ask you some clarifying questions to make sure it understands what you are asking for. Then it would present you with a range of options, and tell you the tradeoffs between them. After you had chosen your preferred solution, it could then tell you where to obtain the resources you need, be it a product, service, training or information you would need to complete the task at hand.

It's only when we see disabled people as strange alien creatures, that it becomes labored to describe what a realistic system should look like "for them." It should look like yours, with a little expansion of data needed to accommodate a larger range of ability levels. For example, the areas of health and fitness, recreation and leisure time seem obvious for rudimentary attempts at a friendly, solution oriented system. Scenario: you get onto the system, it nicely asks what you are looking for; you say that you are bored with your current recreation activities; so it asks you a series of questions: such things as interests and life style, health, physical abilities and limitations, previous activities, economic resources, how far you are willing to travel, etc., and after narrowing things down, it suggests several activity options. You select skiing. It then asks if you would like information on: locations, lessions, equipment, clothing, transportation, clubs, books, magazines, etc. You select equipment. It presents the options: new, used, rental, repair, maintenance, DIY, and so on.

The questions and many of the answers that you would develop for mass market are the same as the questions and answers for disabled people: ability, interest, and resources. If the computer hardware and software for providing information can be thought of as a transportation system, then the system described above could be seen as one truck - a truck that could be loaded with information useable by anyone interested in recreation, whatever their physical ability. If systems are going to be integrated as they are built, we need to have the information "cargo" available for loading in the initial stages of any system's development. Mass market developers are only going to be convinced to include this information in their regular "trucks", if they see disabled people as a market, and the information needed as available; and if we can bring these issues and the developed information to ther attention.

As an ideal, I would like to see as many integrated information systems developed as possible. It is certainly the most cost effective approach to getting appropriate information to disabled people in the community. But it needs to be approached now, as the next generation of information services are developed for the population as a whole. The issues are broad - both attitudinal and information related. But we can, and must, start collecting and organizing the information now, or we will miss the "mass transit" and have to build a separate, and inherently unequal system; one that is likely to require ongoing subsidy from the public sector.

In aiming toward producing "information cargo" for the system trucks to deliver, what kind of data needs to be collected and organized? We are targeting a system that can present all available options and can provide users with enough information to make competent decisions about choices and tradeoffs.

The information about these options is going to have to be easier to retrieve than it is now, if the "delivery trucks" are going to be able to bring it to the community. All of these options can be broken down into categories that are amenable to classification and better organization. A reason to do so, the resources to do it and some imagination are needed.

New developments in software will make it easier to turn currently undigested heaps of data (e.g. the compendiums of single case studies on job accommodations)into forms we can find answers in. By the time the contents for these component databases can be developed, there will surely be mass market "trucks" that will enable an information seeker to ask questions in natural language, while the hardware and software "selects" the appropriate database and retrieves relevant data without the customer needing to learn about or even see the process.

It takes considerable vision to plan for an information system within a still incomplete new Model. During this transitional period of paradigm shifts, it is advisable to work toward both a comprehensive stand alone system, and the development of information cargo that can be loaded into integrated mass market systems. At this early and rapidly developing stage of information delivery environments, the tasks needed for both activities look similar if not identical. There may always be an ongoing need for a separate system for the information that is not readily incorporated into mass markey systems; but that is only going to be learned in time, and with experience in working with regular mass market information channels. And even if a separate information system is needed, the data in it should be as useful as if it were being conveyed in more mainstream channels.

These are curious and unpredictable times when we think about telecommunication and information technology. In our excitement over the new technology's potential, we sometimes seem to have forgotten that we can do something with the information that the machines are processing. However, there is a definite shift occurring. In twenty years we will probably look back disbelieving our current state of naivete. We are only beginning to learn how to use our new information tools to create knowledge from the data we have been collecting. The next generation may laugh at our database access fee structures. Why sell raw data when the "profit", either social or purely monetary, comes from selling analysis, synthesis, and information products that can't readily be developed without database use?

Today, we must continually remember that the underlying question that must guide our future planning is: How can people with disabilities equitably get the services, products and information they need to be fully participating members of society? It is this target that must keep in mind as the pieces and individual components are developed. The danger in not looking forward with this view is that a "non-system" will emerge with huge gaps and overlapping, duplicative parts, wasting the information resources needed for full participation by disabled citizens.

ACKNOWLEDGEMENTS

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THE CENTER FOR SPECIAL EDUCATION TECHNOLOGY

Susan E. Elting and M. Nell Bailey

THE CENTER FOR SPECIAL EDUCATION TECHNOLOGY

ABSTRACT

The Center for Special Education Technology is a national information resource for educators, parents, and researchers using technology with handicapped children. It collects and exchanges information about technology advances and their use with handicapped children and youth. Based at the Council for Exceptional Children (CEC) in Reston, Virginia, the Center was funded by the Office of Special Education Programs (OSEP), U.S. Department of Education in 1984 as a three-year project. CEC is assisted in this effort by JWK International of Annandale, Virginia and LINC Resources of Columbus, Ohio.

INTRODUCTION

The Center for Special Education Technology is a national information resource for educators, researchers and developers, and parents. The overall purpose of the Center is to provide mechanisms for the exchange of information that will increase the quality, availability, and use of technology in special education. The key groups who participate in understanding and promoting the effective use of technology with handicapped children are educators, parents, researchers and developers. If technological advances are to have an impact on the delivery and related services to handicapped children, these groups must be aware of and have access to information that will enable systematic planning for the use of technology.

BACKGROUND

In 1980, the Secretary of Education established a Task Force on Learning and Electronic Technology to advise the Department on the role of the Federal government in promoting the effective use of technology in education. The report of the Task Force cited barriers blocking the widespread use of the new technologies in education and provided recommendations to the Department.

Chief among the barriers cited was the lack of objective sources of information to assist educators, administrators, and parents involved in planning for the use of technology in education. The report recommended that the Department become a conduit for sharing information on technology and its applications in education.

OSEP Initiatives

Since that time, OSEP has placed a high priority on the application of technological advances in the delivery of educational services to handicapped children. Through its entitlement and discretionary programs, the Office has provided the leadership and resources for technology-based research, development, technical assistance, and information initiatives to increase the quality and use of technology. Numerous projects have contributed to the base of knowledge and practice in special education technology.

With the passage of the 1986 amendments to the Education of Handicapped Children's Act (EHA), that commitment to technology-based education will continue. P.L. 99-457 created a new Part G of the EHA that will expand and reinforce the Office's discretionary grants programs for media and technology in four areas: (a) assessment of usage and promotion of effectiveness; (b) design and adaption of new technology; (c) assistance to the public and private sectors in developing and marketing products; and (d) dissemination of related information.

Information Services

Information dissemination projects play a key role in promoting the use of technology in the special education community. In the early 1980's, the first technology-oriented information project was funded by OSEP. Called

Project EduTech, it served as an objective source of information about technology use to educators across the country. In 1984, the Center for Special Education Technology was funded to provide continued leadership and information services to educators, parents, and handicapped individuals. OSEP recently issued a new request for proposal (RFP) to operate the Center for Special Education Technology for another four years through 1991.

METHODS

The Center serves as a specialized information resource for individuals and agencies interested in the use of technology in special education and for social and academic learning in the home. The Center generates information in two primary ways, through the maintenance of a specialized information base and by conducting an annual research symposium on special education technology.

Center Information Base

The Center monitors and collects information on issues that educators and others face as they use technology with handicapped children. The information is organized in a specialized database which is used to provide search and synthesis services on emerging technology research, application, and implementation. The Center regularly monitors a large pool of information and selects items that correspond to the needs of its clientele.

The resources used in updating and maintaining the database include education and technology journals, computer/technology magazines, reports relating to projections and forecasts of technology use, user networks and exchanges, and local education agency applications. This information is organized in a series of files including abstracts, publications, resources, organizations, products, and vendors.

Technology Research Symposium

The Center conducts an annual research symposium on special education technology. The primary purpose of the meeting is to provide a forum for active researchers to exchange information and assess the status of the developing knowledge base. The symposium is also a source of information on the effectiveness and efficiency of technology-based education. Current research-based information is essential for the educators and developers making decisions about the use of technology in the schools.

OUTCOMES

The information gathered in the specialized information base and as a result of the research symposium is used to provide ongoing information services to educators, parents, and others. The Center relies on two proven approaches to information dissemination: direct dissemination and third party dissemination. Specific services include publications, standard mail and telephone, electronic networks, a taped message system and a toll-free hotline.

Information Memos

The Center regularly prepares memos that provide a synthesis of information on a specific topic. Memos may provide an overview of a topic, an annotated listing of literature related to a topic, a list of organizations that provide similar services, or a list of products used in technology-based instruction. Information memos are used to respond to requests and are regularly distributed to individuals and agencies interested in technology use.

Articles and Features

Educators seeking information about technology advances and applications rely heavily on education and technology journals for current information. The Center prepares synthesis articles for publication in selected professional journals. Such articles have appeared in *Teaching Exceptional Children*, *Class-*

room Computer Learning, School Administrator, and The American Educator.

Electronic Bulletin Board

The Center operates the TECH.LINE bulletin board on SpecialNet. The bulletin board serves as an electronic newsletter that features a new technology related topic each month. Information items, related to the topic, are drawn from the database.

Taped Message Service

The Center operates a telephone-based information service, known as TECH-TAPES, for educators, parents, and handicapped individuals. The system provides callers with a choice of over 200 individual messages in 27 different categories. The messages are intended to provide an introduction to a specific topic. The service operates 24 hours a day and can be accessed toll-free by calling 1-800-345-TECH.

Telephone Hotline

The Center's toll-free number is used as a hotline for information requests and consultation. The hotline operates on weekdays from 1 p.m. to 4 p.m. Eastern Time.

These services offer a balance of easily accessible mechanisms that take advantage of traditional and technology-based alternatives. The Center's services are widely used by individuals, state education agencies and technology centers, universities, and other associations. Interested readers can contact the Center by regular or electronic mail or by phone.

For more information, contact:

Center for Special Education Technology
The Council for Exceptional Children
1920 Association Drive
Reston, VA 22091
Telephone: 703/620-3660
Toll-free: 1-800-345-TECH
SpecialNet: CEC.TECH

Susan E. Elting, Project Director and M. Nell Bailey, Program Specialist, The Center for Special Education Technology, Council for Exceptional Children, 1920 Association Drive, Reston, VA 22091.

USING VOICE MAIL TECHNOLOGY TO AID THE DISABLED (AIDLINE)

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Associated Enterprises, Inc.
120 Admiral Cochrane Drive
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ABSTRACT

Voice messaging technology using its audiotex feature is an ideal medium to make essential information on assistive devices and procedures, government rehabilitation programs, and a wide range of helpful information available to disabled people. Those to be reached need no equipment other than a telephone. A total of 164 messages in some forty general categories has been developed for AIDLINE. The response to this program was exceptionally high. Twenty-seven percent of the brochure mailings that announced the program resulted in messages being called up by disabled or elderly persons, or by people calling on their behalf. The program categories ranged through such subject matters as: Aids for the Blind, Computers, Eating Aids, Information Services, Living Alone, Walking Aids, Work/Study Aids, and a great many more. The technology is much broader in scope than audiotex. It allows a full range of information exchange. (End)

Associated Enterprises, Inc. of Annapolis, Maryland, has had considerable experience in developing projects relating to the physically impaired. Although most of the company's business is in the private sector, projects involving disabled persons have all been Federally funded. AIDLINE was the first. It was sponsored by the Human Development Services, U.S. Department of Health and Human Services. A segment of the contract ABSTRACT follows:

> By applying an adaptation of voice messaging technology in use by this firm for small businesses, we propose to establish the technical merit and feasibility of making available to the elderly and disabled, medical and geriatric institutions, family members, and other interested individuals and groups, a wide range of information concerning specific categories of devices put on a series of computerized telephone tapes, and made available at no cost to individuals (elderly, handicapped, professional persons, family, friends, etc.).

Voice messaging is a relatively new technology (the first commercial system was installed in 1980) and few people are familiar with what it is and how it works. To add to the confusion, this technology goes by different names, such as voice-store-and-forward, voice messaging, and voice mail. By any name, it is essentially a technology based on a pushbutton phone and a computer. The voice messaging system currently in use by this firm was produced by VOICEMAIL® International, Inc. of Cupentino, California.

Voice messaging is related to electronic mail in that both require electronic storage and transmission of messages, and both can be accessed by the sender or receiver. The big difference is that voice mail requires no keyboards or any equipment other than an ordinary telephone.

Associated is pioneering a technology with its voice mail capability, in that pre-recorded taped messages helpful to target audiences are available at no cost to the consumer. This endeavor had been well established when AIDLINE became operational.

The centralized computers and digitized voice converters are located in Associated's office in Annapolis, Maryland. This complex of equipment permits telephone users to listen to prepared messages in the voices of the professional recordees 24 hours a day, seven days a week, the year round. And distance is not a factor. The messages can be accessed from any state in the union, and internationally from any place there is a telephone.

The project provided for feedback from the listeners through a live operator HELPLINE which was accessible by toll free number to anyone. This feature of the project was the only feature not computerized.

A computerized Suggestion Box was available for input from AIDLINE users who wanted to comment on and make suggestions about the system.

The hypothesis proposed to be tested was:

> There is a large and important body of self-help and other aids and devices in isolated use that once "discovered" can be made readily available through telephone tape technology to benefit the elderly and handicapped nationwide.

One important characteristic of the project was the recognition that the maladies of aging also afflict many young and middle aged people, usually due to congenital defects, accidents, injury, disease or premature physical degeneration. Under this premise the project proposed included both the elderly and the disabled.

A major effort, key to successful conduct of the entire project, was the development of a large data bank of aids, devices and independent living procedures. The first step entailed location of any existing data banks that might give us a head start. The most notable one, readily discovered, was the ABLEDATA bank of the National Rehabilitation Information Center. This and other sources were of limited value for AIDLINE. They were not on target, since the search was for a great number of commercialized and non-commercialized items and procedures while the computerized data available was intended to show the great variety of sources from which specific devices could be acquired.

Primary and secondary research that had not previously been attempted was conducted. The National Library of Medicine and the Enoch Pratt Library in Baltimore, Maryland, were rich sources of secondary research concerning organizations, foundations, and firms to contact.

Primary research included a direct appeal to the public for information. News releases were sent to 349 local and national publications. It appeared in numerous Baltimore-Annapolis-Washington newspapers and in national publications slanted toward the needs of the elderly and disabled. A few important nationwide organizations among the considerable number that put the release in their newsletters and/or magazines were:

- National veterans organizations such as the Veterans of Foreign Wars (VFW)
- National organizations dedicated to helping the disabled such as Rehabilitation Literature, published by the National Easter Seal Society, The National Center for a Barrier Free Environment Report, Vol. 9, No. 5, and
- National Associations such as the American Association For the Advancement of Science, in their Bulletins on Science and Technology For the Handicapped, Vol 4, No. 4, Fall 1984

The nationwide search conducted through these dozens of other widely read (by the elderly and handicapped) publications, resulted in a surge of correspondence, which in turn built up a considerable data bank of aids, devices and independent living procedures.

A number of firms manufacturing and/or distributing aids and devices were identified. Catalogs were obtained from each of these, whether they offered a single item for the aged or disabled, or were dedicated solely to marketing items for these groups. A file of catalogs from firms was accumulated and added much to the collection of data.

Collecting data for this project was a very satisfying experience. Little known but useful aids and devices were identified in far greater number than could possibly by used. One discovery of great interest was that the British have done far more than has been done in our country to publicize, and make available to those who need them, aids and devices that are available or which can be fashioned to assist elderly and handicapped people. The nationalized system in Great Britain has, apparently, encouraged this with a network of government agencies involved.

It became a challenge to demonstrate a system that will encourage people to help other people, by providing the necessary information widely through telephone tape technology with little or no government involvement.

Efforts to collect data were most successful. Agencies and organizations of many kinds were eager to cooperate in this effort, although efforts to collect information on a wide variety of obscure aids revealed that only isolated pockets of activity existed in the United States. As these were located, it was found that people were most eager to share their information.

The basic premise on which the project was based: "That there exists a vast reservoir of little known aids and devices that could be of immeasurable benefit to thousands of elderly and handicapped people, if their existence were to become known", was proven to be valid.

Making information selectively and readily available to assist in reducing accidents for the bold, and enabling the weak to function, are missions of the telephone tape technology, which is the basis for current development of private capital commitments for commercial applications.

Books (and only very few) are available that describe many of the aids and devices. But books reach only a small fraction of those who have a need (they usually collect dust on the shelves of provider libraries and are used, if at all, by the institutions' technical and professional personnel). Books do not allow the individual to be selective about the information he or she seeks. A telephone tape system based on highly specialized topics--cooking, dressing, mobility, tooth care, bathing aids, and many other specialized subjects, is simple to access. It allows the person with the need (or the person or institution caring for people) to be better able to care for themselves, or be cared for.

In order to assure that the most technical and professionally oriented tapes would have the input of people knowledgeable in the various disciplines involved, an advisory group for review of scripts was established. Those professional persons who agreed to participate were:

NAME	ORGANIZATION
Ms. Carol Williams	Meridian Nursing Home Severna Park, Maryland
Mr. John A. Lancaster	Director of the Office of Coordination of Services to The Handicapped State of Maryland
Mr. Elmer Bartels (and staff)	Commissioner, Mass. Rehab. Commission, Boston, Massachusetts
Mrs. Patricia McGarty	Deputy Director, Department of Aging, Anne Arundel County, Maryland
Mrs. Jean Miller	Life Support Program Anne Arundel County, Md.
Mr. Michael Lechner (and staff)	Executive Secretary Kansas Advisory Committee on Employment of the Handicapped, Topeka, Kan.
Ms. Marion Hall	ABLEDATA Computer Services Washington, D.C.

NAME	ORGANIZATION
Ms. Jean Vieth Sargent	Author of "Handbook for the Elderly and Handicapped", Iowa State Press, and Newspaper Columnist

As a result of the evaluations and informal feedback, it was determined that future tapes should reflect the "lessons learned" where possible. Some of these are:

- Produce shorter tapes, no more than 3 minutes.
- Include fewer aids, devices and procedures tips on each tape.
- Attempt to give references and sources on tapes.
- Develop tapes giving sources of additional information, such as: transportation for the elderly, latest resources for specific disabilities, manufacturers of equipment, etc.
- Prepare tapes discussing organizations and agencies, both public and private, that offer services and assistance to the elderly and disabled.
- Develop tape topics that include housing availability, from senior apartments to nursing homes, and psychological counseling and inspirational tapes.
- Consider tapes concerning the availability of devices - "Where to shop for aids".
- Consider offering hard copy of scripts when asked for.
- Consider whether the name AIDLINE should be changed. (One caller thought it would be confused with the disease AIDS).
- Write some tapes around specific manufacturer's products and give sources.
- Avoid erroneous words such as "mute" which one caller alleged to be objectionable.
- Avoid stilted language. Use simple direct narrative.
- Avoid the words "inspire or "inspiring".
- Be upbeat in developing tapes. Stress overcoming disabilities and getting out of the house if possible.
- Obtain TTY number so deaf can receive information.

The Health and Human Services contract listed key questions to be answered. These are specifically addressed below:

Q: Are there numerous important and virtually unknown devices and aids "out there" awaiting discovery?

A: This can be answered with a resounding "YES". One hundred sixty four messages were written and material collected is sufficient to support many more.

Q: Given their existence, is it possible to identify those aids and devices for which a real need exists among the handicapped aged?

A: The number of calls generated were evidence that there is a great need for the kind of data included in those tapes. Much more helpful information was gathered and experience shows that the well is almost bottomless.

Q: In a research feasibility study of this nature can sufficient information and data be obtained to permit exploitation for the benefit of the nation's handicapped?

A: Without doubt. The evidence is strong that the information can be obtained for a full scale national program and made available nationwide.

Q: Are there unanticipated barriers to either locating or obtaining the necessary information and data?

A: It was more difficult to obtain useful data from private solicitations than was anticipated. Many persons withheld data hoping to capitalize on their own ideas. This was an unanticipated barrier; however, the great volume of little known aids and devices identified, (especially from foreign sources) more than made up for this problem.

Q: Is it likely that sponsors (providers) will be interested in eventually commercializing the system?

A: Potential sponsors have had the opportunity of fully testing the system for themselves and commercialization from several sources is under negotiation.

Q: Is it feasible to make the system perpetually self updating through an "idea line" matched with the "HELPLINE"? (HELPLINE is a call-in feature where additional referral is obtained on an aid or device described in the tape library).

A: An evaluation service (the test version of the "idea line") is an integral part of the project. Many suggestions and constructive criticisms were received. It is noteworthy that much of the evaluation line feedback was from people in the business of professionally serving the elderly and/or disabled. An "idea line" was a part of the system. It is called the "Suggestion Box".

Other contributions came with the success of the tape system. The identification alone of aids and devices that could be candidates for commercialization might well be an important spinoff. Data obtained from months of system operation should make clear, probably for the first time, the areas where the greatest needs--and therefore the greatest item commercialization efforts--are. It is conceivable that professionals will see the system as an important adjunct to their services. Rehabilitation institutions using the system (or perhaps even sponsoring it) may be better able to care for their patients, or better still, may find it possible to release some to live at home.

The tape system carries its admonitions concerning approval of aids by professional personnel caring for the users. Often, even the simplest aids can be contra-indicated for some users. For the most part, however, the aids and devices were chosen partly on the basis of general need and simplicity of use.

No class of person, no geographical region, is exempt from the need. It is a national problem, and telephone tape technology can be of national benefit to cope with the growing need.

Designing a Database: theoretical considerations

Robert Egert, MD; National Rehabilitation Hospital

Abstract: Models of database representation which have been explored both theoretically and through implementation include the hierarchical, network and relational database models. The formulation of a working database requires attention to potential problem areas including data replication, data representation, access speed, data entry validation, query complexity and optimization, as well as levels of user skill and the design of the user interface. This paper presents an overview of these models and problems.

Abstract models of database representation exist which have been explored theoretically and implemented. These models are of hierarchical, network and relational databases. More recent designs and implementations include full text retrieval systems and AI interfaced dedicated database machines. Each of these models attempts to satisfy the user's desire for logical, efficient, accessible storage of information. These systems must take into account both software and hardware requirements to achieve these goals. Additionally, as demands on the systems have become more substantial there has been a recognition that data representation and intelligent computer based retrieval (and perhaps organizational) strategies may be useful. There has been limited documentation of the utility of some of the systems not withstanding their ubiquitous presence in the personal computer market.

This paper will briefly present an overview of the processes engaged in by all types of database systems, the organization of the three canonical forms of databases, an introduction to problems encountered by all database systems and finally a summary of steps a database organizer should perform prior to bringing a system into existence. In general, the term database will be be used in the sense of model of organization while a database system will refer to the implementation, via hardware or software, of the model.

The general classes of activities which all database systems must perform which include:1) navigation, 2) insertion, 3) deletion, 4) selection and 5) modification. Navigation is the process by which information is located in the database. At the most naive level the database system might search every entry for a match. For larger databases, indexes, which list each unique entry in a specified field and its location in the database, are created to speed the process. Insertion is the process by which new information is added to the database. Of concern here is that as additions are made, indexes, if they exist, must be updated and the physical storage of the information in an efficient manner must be accomodated. At the time of additions, data verification, if indicated, is performed. Deletions produce some of the same complications as insertions but in addition issues of dependency of data elements on other data elements must be addressed. For example, if the laboratory stops performing a test it may need to keep the information regarding normal laboratory values accessible as the integrity of patient files may depend upon being able to document not only test values but also the normal range of values for the test. Selection is the process whereby items to be choosen are designated. Modifications or changes in data elements can be a particularly troublesome process unless the data is organized so that every instance of the item to be changed is readily and completely available. For example, if the laboratory changes the name of a test from X to Y the database system may need to find every occurrence of the old designation and change it.

Every database system needs to deal the the above operations and each will have a command to perform it. Navigation is generally associated with a command with the sense of FIND or GET or LOCATE or RETRIEVE. Insertions are generally accomplished with commands of the form ADD or STORE or APPEND. Deletions use commands such as DELETE or REMOVE. Selections use commands such as WHERE followed by the name to the choosen variable and the range of values to allow. Modifications take place with command as MODIFY or REPLACE. Even data base systems which do not explicitly use these commands must perform the operations. In addition to performing these operations, each database system (unless it is non-procedural) must allow control of the steps taken to accomplish them. A set of control commands that allows looping, conditional execution and branching, simple or complex mathematical functions and output formatting and printing is usually required. An awareness of the general class of procedure being requested may make the command structure of the particular application more understandable and the documentation easier to use.

Hierarchical databases provide the most intuitive approach to information storage and access. The notion of properties broken down into ever more elemental units provides a familiar paradigm for organization. Hierachical databases, however, may impose severe penalties due to the storage of redundant data and significant overhead in accessing or sorting data elements at lower levels of the tree. The efficiency of using a hierarchical database depends upon the degree to which the the data is actually hierarchical in structure. In general simple kinds of information structures lend themselves to this kind of organization. For more complex tasks or when the amount of information can be expected to grow, hierarchical database are not as useful. An example of a hierarchically structured indexing system is the Medical Subject Headings (MESH) used by the National Library of Medicine. This system is used as an indexing vocabulary for the medical literature. Its structure has developed somewhat in imitation of the organization of medical knowledge but often frustrates the user because of vagueness or over preciseness and its relative inability to allow the description of related concepts directly. In hierarchical systems this inability to define relationships between objects not sharing a commmon ancestor and the large number of siblings that may exist beneath a given level are theoretical and technical barriers to their use.

Network database models provide the greatest flexibiity in representing complex interrelations among data elements allowing a virtually unlimited ability for an element to reference or depend upon another element. Some view hierarchical databases as a simple form of network databases. The designer provides a measure of organizational intelligence to the database through a symbolic representation of ideas. Generally, the structure of the relationships must be defined before data is actually stored to avoid costly, or impossible, reindexing. The responsibility of the designer to monitor the correctness of these relationships, which may develop in non-trivial and inapparent ways, is substantial. The network design perhaps most stringently forces the user to invest in the conceptualization of a database prior to its implementation.

Relational databases are the most familiar model at the present time. They organize data into interrelated tables. The designer separates out independent chunks of information thus abstracting conceptual units. The system of interrelating these conceptual units is usually not defined until the user requests it, thus allowing and forcing the user have responsibility for the definition of the more complex ideas. The method by which the user connects tables is called a join and it acts by matching fields specified by the user and selecting items of information according to the the criteria the user defines. Perhaps the most frequently cumbersome aspect of using a relational database is that if a query is poorly formed and references unrelated tables the user may have to sit through a virtually endless and useless return of unwanted replies.

The formulation of a working database requires attention to potential problem areas in cluding data replication, data representation, access speed, data entry validation, query complexity and optimization, as well as levels of user skill and the design of the user interface. These problems cut across hardware and soft ware choices and make logical decision making complex. An overview of some of these problems is presented.

Data replication is the problem of repeated information. In virtually any database there will be repeated information if only for optimization of response speed. However, two significant problems may occur. If the repeated information is large it will take up storage space and will tend to reduce the performance of the system. Secondly, if a repeated item needs to be changed, the user must make certain that every instance in the database is changed in order to maintain the integrity and correctness of the database. If, for example, one were to create a database listing all the manufacturers of adaptive equipment, their address and the items they manufactured, it would be wasteful to repeat the address of the manufacturer for each item he provided (especially if he had multiple addresses) and it would be cumbersome to change the name for the manufacturer. The cost (in terms of lost efficiency) of data replication is particularly dependent upon the implementation since there are a variety of storage schemes to reduce the overhead.

Data representation is important in

several ways. First, the user must be encouraged to adhere to a standard vocabulary or there will be problems when he tries to retrieve information. One of the major drawbacks to any full text retrieval system (as users will attest) is that since similar concepts can be expressed multiple ways there is always a tradeoff in terms of relevance versus completeness in the response to a query when vocabulary and indexing languages have not been standardized. Secondly, storage requirements and indexing may be significantly improved by encoding certain information particularly if the information is slowly changing over time and consists of long alphanumeric phrases. Diagnostic categories are prime targets for encoding schemes.

Access speed is an issue of particular importance in on line database useage. Users quickly be come frustrated by slow responses. There are two components to increasing the efficiency of access. Firstly the database must be organized and indexed with an eye toward the type of queries that will be made against it. Indexing frequently used terms and understanding the details of the storage scheme used by the database will be helpful. The second area of optimization concerns the formation of the queries. In the most sophisticated systems queries are processed to select the most efficient retrieval strategy. For simpler systems the user should be educated to use all available options such as proper use of the controlled vocabulary, narrowing the scope of the query (for example, restricting a query to data on 'humans only', if applicable) and the optimum use of connectives such as AND and OR.

Data entry validation is the step where in the use of a controlled vocabulary, gross typographical errors, and improbable situations (such as age equal to 999) should be addressed. This verification process is essential for databases that are anticipated to exist for long periods of time, will have large amounts of data or will be used by multiple users since under these circumstances the chance of data becoming corrupted is increased. This verification may significantly slow data entry and should probably be left for critical items only. The use of menus of allowable selections is one method of entry validation.

User interface issues pertain both to the appearance and ease with which the database presents itself to the user but also to the sophistication which the designer is willing to provide the user in terms of help facilities, error trapping and screen or output formatting. There is little more frustrating than to watch data either scroll off the edge or bottom of the screen or to be unable to examine a prior query to emulate its success or to avoid its pitfalls.

Several caveats are in order before bringing a system up:

1. Outline the structure: every database rests upon the assumption that there are real world contraints which operate on the data and interrelate aspects of it. An understanding of the structure of the information and a modelling of the information according to the users' perceptions makes later modifications, should they be requested by the users, far easier. Large structures being used by many different classes of users may require that the designer consider defining a global construct which is presented in different ways to the different classes of users. For example, a patient record may contain both clinically and administratively relevant information that does not overlap in all areas. Information selected for its interest to certain groups of people is said to be a view. Views should also be constructed with concern for the users' perceptions of the organization of the data. The understanding of what constitutes the necessary pieces of information and how they are related is what distinguishes a good database designer from a poor one. It may be possible to correct or modify the database structure after information is captured but is is usually painful. Many application packages provide the usar with an interface that allows the design of the database to proceed smoothly-- none however will guarantee that the structure is conceptually sound.
2. Choose a vocabulary: in the long run there is no way to accumulate information that will be accessible later unless all users agree to use the same, and hopefully minimally required, terms. The problem grows with the number of users and the frequency with which users change.
3. Document the database: the rationale for the structure of the database and the choice of vocabulary and the steps taken to insure the integrity of the database should be in writing.
4. Test the database: small samples of data should be entered and queries with known answers should be submitted and ouput formatting checked.
5. Educate the users: those entering or retrieveing information should be aware of what to expect.
6. Anticipate increased user sophistication and utilization and the request for more options in all areas.

ASSISTIVE DEVICE INFORMATION SERVICES IN MICHIGAN

A.S. Ensign and D.E. Heiner
PHYSICALLY IMPAIRED ASSOCIATION OF MICHIGAN

ABSTRACT

In Michigan, handicapped persons of any age are free to consult with a triad of resources which focus on easy and functional access to the environment. PIAM, the Physically Impaired Association of Michigan, a state-wide advocacy organization, is the legal entity for the PAM Assistance Centre (PAM) and the Living and Learning Resource Centre (LLRC). Information, demonstration, and consultation services are offered without charge to handicappers whom technology may serve. Providing individualized and caring assistance to clients is the prime objective. Additionally, programs, demonstrations, exhibits and publications are offered. PAM stresses the light-tech resources, with emphasis on information concerning education devices, adaptive recreation, and aids to daily living. The LLRC addresses computer access and varied high-tech devices for mobility limited, multiply handicapped, and blind clients.

INTRODUCTION

Michigan offers to persons of all ages a comprehensive information, demonstration, and consultation resource on assistive devices. The Physically Impaired Association of Michigan (PIAM) functions as a statewide advocacy organization for physically impaired persons. It is also the legal entity for two "sister" services, one for light technology, the PAM Assistance Centre (PAM), and the other for high technology, the Living and Learning Resource Centre (LLRC).

This unique, composite resource did not spring into being by the golden wand of a large grant, nor was it a mandated service. Instead, it evolved out of the expressed needs of parents of handicapped children, of many professional persons, and of handicapped persons themselves.

RESOURCE SERVICES

PIAM, The organization

In 1973 a group of professionals and parents concerned with "physically impaired" children began having mini-sessions at meetings around Michigan, in preparation for founding a new organization. Mutual support and education, political visibility, and practical assistance were the goals - "to improve the quality of life. . ." and so the Physically Impaired Association of Michigan (P.I.A.M. called "PAM") was born.

It soon became evident that many handicapped adults as well as persons concerned with visual, auditory and multiple sensory impairments were relating to PIAM's objectives. To concerns for children were added the silent, often poignant, needs of the elderly.

The purpose of the parent organization is still to bring persons with mobility or sensory limitations into communication with each other so that they may learn to better cope with life. Disabilities may be slight or severe. Financed only by a slender dues structure, the organization has maintained its vitality through the dedication of its officers and other volunteers.

From the beginning, it was evident that the sheer lack of information on available services and resources was a major drawback for parents, handicappers and would-be service providers. The PAM DIGEST emerged, and for a number of years it addressed this need to its several hundred subscribers around the state. Statewide meetings addressed a wide range of issues, most of them later found to be pertinent, as well as "ahead of their time," in problem resolution.

PAM, The light-tech centre

By 1979 the information explosion was already taking on new dimensions. There were more organizations, more newsletters and resources. Two things were becoming clear to PAM's founding friends: first, periodic meetings were not sufficient for information dissemination; and second, there was no coordinated information service on assistive devices - a monstrous gap unaddressed.

A landlord was found who offered a first floor apartment in Michigan's capital city at a very modest charge, thus housing the first PAM Assistance Centre. This "bootstraps operation," conceived and staffed by PAM volunteers, conducted a statewide needs assessment, and began by assembling a variety of small assistive devices for blind, physically and multiply handicapped "clients." A special educator and a rehabilitation nurse (both volunteers) were the Centre's first staff, augmented in the fall by a CETA secretary. Visitors coming up the ramp to that older home housing PAM found a cup of coffee and knowledgeable, concerned persons there to help them - without charge.

Then, as now, the PAM Assistance Centre provided information about assistive devices old and new - what they may be, what they cost, how they might be secured. Centre staff specializes in problem solving on a highly individualized basis, and at no charge to any of the 1500 or so clients currently served in one year.

All ages are eligible for service. The special education population (0-25), rehabilitation clients, and older persons are included. Physically handicapped, deaf, blind, or multiply handicapped individuals often find the Centre helpful. Persons with cerebral palsy (CP), arthritis, strokes, muscular dystrophy (MD), and multiple sclerosis (MS) can benefit. There is no "red-tape," no set of qualifications to meet.

The PAM service is of particular value to persons familiar with handicapper needs and responsible for their welfare in one way or another. Persons skilled in therapy, nursing, special education, vocational rehabilitation, and other helping professionals are on a very tight time-schedule. Technology is developing very rapidly, while client needs continue to be personal and highly individual. The PAM professional staff helps other professionals "put it all together."

In order to provide up-to-date and accurate information for PAM's clients, a comprehensive library of resources has been initiated at the PAM office. Information on products, 15,000 or more; companies, 2,000 of them--is crucial, yet the market is constantly in flux. AbleData, a computerized database on assistive devices, is one helpful resource, but there is really no short cut to providing up-to-date, reliable assistive device information.

This assistive device information is shared also with interested persons through the PAM REPEATER, GRAM from PAM, and PIAM NEWS, all of which are issued periodically to PIAM membership. REPEATERs focus on such varied topics as camping, adapted toys and recreation, incontinence, warning systems, and adapted clothing.

The LLRC, The high-tech centre

A third component of Michigan's assistive device resource service was formally opened in October, 1986. The Living and Learning Resource Centre (LLRC) enjoys barrier-free housing in the Library of the Michigan School for the Blind, adjacent to the PAM Assistance Centre. Many mutual clients are served.

The LLRC provides a comprehensive information and demonstration center on the selection, development and/or adaptation of high technology for educational and vocational purposes. The special focus of the LLRC is low-incidence populations, such as individuals with visual or multiple impairments. The LLRC offers individuals or agencies the opportunity of obtaining information on or previewing adaptive equipment and software. The LLRC houses a variety of computers, adaptive accessories and communication devices.

The LLRC has five major goals: (1) to serve as an information clearinghouse; (2) to provide professional development training; (3) to conduct diagnostic assessments; (4) to evaluate equipment for the handicapped; (5) to identify modification of tools and/or the work environment for individuals with physical handicaps.

A Facilities Grant from the Michigan Commission for the Blind has made possible a wide assortment of equipment and software specifically designed for individuals with visual impairments. Major funding for the LLRC consists of P.L. 94-142 monies designated by Special Education Services of the Michigan Department of Education for the LLRC as a "State Initiated Project." Since the concept is overall service, funding from varied sources will be required to insure the ongoing expansion of the LLRC.

DISCUSSION

Some observations shared out of PAM's eight years of device information service follow:

*Since devices, and companies themselves, are in and out of the market daily, a dedicated device information service becomes a true necessity.

*As the service becomes better known, the demand increases, and more complex problems are posed. The technology explosion has particular significance to handicapped persons.

*The extent of the disability may or may not be a significant factor in determining the serious nature of the need for help.

*Many people exist miserably because it never occurred to them that there might be a device helpful to them.

*A piece of equipment may be very simple, but no one may have thought about using or devising it for that individual.

*Creative ways of blending equipment funding sources may make the "impossible" possible.

CONCLUSIONS

In summary, the Michigan experience attests to the effectiveness of an overall system of dissemination of information on assistive devices. It is only within the total life setting that technology will truly and naturally find acceptance. Provide a communication network of caring people, an environment at home, at school and in the work-place where unique tools of self-accomplishment are available to the handicapped person, and insure ongoing access to the most modern of any of those devices.

The dream may be within reach at last.

ACKNOWLEDGEMENTS

The LLRC represents a state initiated project awarded to the Physically Impaired Association of Michigan by the Michigan Board of Education, with additional funding from the Michigan Commission for the Blind, Michigan Department of Labor.

Funding from the Michigan Department of Education allotted to the "Center for Adaptive Aids" is also the major source of support for the PAM Assistance Centre, along with a grant from the City of Lansing, PIAM memberships and other donations.

The Physically Impaired Association of Michigan is a 501(c)3 and also a 509(a)1 non-profit organization as recognized by the Internal Revenue Service. It is supported through personal memberships ($7) and organizational affiliations ($25).

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CLOTHING FOR SPECIAL NEEDS: AN INFORMATION ARENA

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This project focused on developing an information center and service to provide alternative clothing solutions for special needs. Survey data substantiated the distinct problems to be addressed and a variety of viable options to achieve the solutions. The use of videotape programs, instructional pamphlets, slide presentations and displays plus sample garments are available for individual, professional and group use.

Physical limitations necessitating special clothing needs may be classified by muscular weakness, joint limitation, limitation in range of motion and reach, partial or total lack of coordination, poor balance, spasticity, use of braces and prostheses, paralysis, deformities, amputations, and single handedness. Clothing choice, clothing adaptation, and clothing devices can increase independent living skills of persons with physical limitations in dressing and undressing (1).

Clothing is important to the adjustment of physically impaired people for at least two reasons: 1) Functional clothing that is designed and constructed to accommodate physical limitations reduces dependence on others for dressing and undressing; 2) socially acceptable clothing that reduces perceptual deviance promotes positive social interaction, thereby aiding in social and personal adjustment (2).

The objectives of this project were focused on the need to educate and motivate the ever growing handicapped/elderly population, through the use of different instructional media, to become more self-reliant and aware of fashionable dress alternatives, dressing approaches and devices that are available to them. The project also aimed at providing professional/paraprofessionals/attendants/parents and the handicapped individual with a better understanding of clothing selection and specific garment style, features and/or simple garment adaptation/modifications that would provide greater comfort and facilitate dressing problems.(3) The merit of the project is found in its ability to provide the handicapped/elderly community with dressing alternatives and garment modification that will enhance their independence on a level that is obtainable.

A survey of over 3,000 Arizona residents, most of whom have arthritis, was conducted in November, 1985. A reponse rate of 21% was yielded without followup efforts. While arthritis is disease specific, the physical limitations necessitating special clothing needs are not. In this survey we attempted to assess abiliites by parts or joints of the body affected. The importance of the affliction is that it hinders or limits mobility and the ability to attend to daily living needs.

When 789 of Arizona's arthritic men (21.9%) and women (78.1%) responded to the 1985 clothing questionnaire they were quick to share some serious concerns as to how arthritis affects their clothing and dressing problems. Respondents reported difficulty in purchasing clothing mainly due to dressing problems, fit, sizing differences, lack of comfort, and unsuitable designs. Fasteners seemed to be a continuing and statistically significant problem with small buttons (65%) being, by far, the most common problem (Table 1). Center front openings were prefered by a large majority. It seemed evident that women have more problems with clothing than men, which is not a surprising observation as men's fashions traditionally have been more functional in design. These statisitics did not vary too greatly from earlier similar research done by Reich using a handicapped population that was not disease specific (4). One important area often alluded to in "other problems" by respondents included the problems relating to feet and footwear--where to get decent looking shoes that fit well, feel comfortable and styles that can be easily fastened.

The purpose of creating an information arena was twofold: 1) to establish a clothing resource center at the Harrington Arthritis Research Center; and 2) to design and implement an educational program via visual, audio, and group presentations. Based upon the needs documented as a result of the survey, new video tapes (including one on shoe selection), slide series with narrations, leaflets and fact sheets related to clothing and dressing needs and instruction sheets for specific garment modifications were developed. Actual physical examples of fashionable clothing items and garment modifications were assembled.

The collection includes displays, fashionable ready-to-wear clothing designs that incorporate self-help design features, and adapted clothing from ready-to-wear. Special functional clothing, dressing aids, and adaptive devices that enhance ease of dressing were obtained from resources that offer Clothing for Special Needs.

The Clothing Resource Center, staffed by auxiliary service persons and clothing consultants, serves as a clearing house for information related to clothing and dressing needs. Displays, leaflets, video tapes, slide series with narration and actual physical examples, to demonstrate the various modification techniques, are available. Reference books and special needs clothing catalogs are available in the library of this community resource center. Materials are housed in a central area, available to individuals from the public, professionals who wish to research for specific case solutions, and trained facilitators who present group seminars and deliver outreach programs.

Follow-up evaluation of impact or use of programs presented or direct inquiries and consultations with consultants is ongoing to assess and further refine the materials and delivery mode. Participants and/or clients are requested to provide names and addresses and a short questionnaire is mailed 3-4 weeks after the initial contact. A stamped return envelope is provided to encourage response.

Daily living activities are experienced by all of us throughout our life cycle. When they are complicated by a physical handicap, the challenge of those activities is magnified. Personal needs include a variety of activities relating to the selection and care of fashionable clothing items, and the task of dressing and undressing. It is the responsibility of professionals/paraprofessionals/attendants/parents to provide better understanding, through the use of different educational modes, of clothing selection for specific problems, special clothing adaptations, special clothing, and devices that are possible and available thus motivating the physically impaired individual to become more self-reliant and aware of dressing alternatives and devices.

Resource centers such as the one described can help serve to inform individuals, paraprofessionals and the many professionals in close proximity to clients with daily living needs of fashionable clothing ideas to relieve dressing and undressing problems of physically impaired individuals. The Resource Center provides a stepping off place to begin an information outreach to persons requiring such information thus raising the consciousness level of all persons involved in any dimension with the handicapped and/or elderly.

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TABLE 1. Frequency of Response for Fasteners and Their Location for People with Arthritis.

Difficulty with fasteners	
Buttons 1/2" or smaller	65.9%
Buttons 1: or larger	17.7
Belts and loops	25.0
Ties or eyelets & lacing	36.0
Snaps	39.3
Hooks and Eyes	37.0
Velcro	4.6
Zippers	28.6
Best location	
Center Front	80.8
Center Back	2.8
Side	21.4

N=789

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Special Interest Group 16
Gerontology
Chair: David Cooper

Progress in Preventive Techniques for the Elderly

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The primary function of Rehabilitation Engineering is generally thought of as the design, analysis and delivery of devices and procedures for enhancing the quality of life of the disabled. Augmenting reduced function due to disability is the focal point of the Rehabilitation Engineer's attention. One aspect that is gaining attention is the prevention of disability. Not only is the safety of the products we design an issue, but also the prevention of injuries that result in disability.

A large portion of the elderly are of sound body and mind, but have a gradual and relentless loss of function. At some point the health of these people becomes compromised. Age related physiological and psychological changes such as decreased vascular capacity, bone degeneration, and reduced cognitive ability may increase their susceptibility to injury. Though many become institutionalized due to losses in physiological function, a large portion have traumatic injuries which cause considerable suffering and expense.

The elderly who are already disabled are susceptible to the same injuries as younger disabled people. These would be problems such as pressure sores, development of deformity, and traumatic injury.

The growing population of elderly have an increasing need for preventive techniques and devices. Prevention of injury is one of the keys to improving the well-being of the able and disabled elderly and to reducing demands on the medical delivery system.

Posture control and pressure management through special seating have always had preventive components to them, as have various aspects of mobility design. Other areas of design for prevention of injury have primarily addressed reducing the possibility of falls. These included architectural factors such as handrails and restroom fixtures.

Recently, there has been increased interest in design for reasons of prevention. Crash tested car seats for the disabled, analysis of falling mechanics and subsequent design, and methods of averting dangerous wandering behaviors have all recently received interest.

The papers assembled for this symposia on the elderly address the issues of prevention analysis and design starting with an overview of the relationship of technology to the elderly. Also included is a paper on information and funding resources for researchers in the field of gerontology.

Wandering Behavior of Elderly Nursing Home Residents:Evaluation and intervention

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Abstract

The purpose of this study was to determine if the wandering behavior of elderly nursing home residents could be modified through the use of stimulus control. Nine male nursing home residents who were identified by nursing staff as wanderers were video taped for 7 weeks. Three locations defined as off-limits to the subjects were monitored. Two conditions of stimulus presentation - verbal feedback (week 2 & 4) and an aversive tone (week 5 & 7) - were evaluated using a single subject design and A-B-A-B reversal technique, where A represented the baseline condition and B the intervention. Only subjects in which the verbal feedback did not reduce their wandering behavior to criterion were exposed to the aversive tone. A variety of behaviors, including encroachments of caregiver restricted areas, were coded by two independent raters and analyzed. Results and conclusions of the study will be presented at the RESNA '87 Annual Conference.

Wandering is a serious behavioral problem for both caregivers and elderly persons. It may be exhibited as an agitated pacing within a relatively confined area or, of greater concern, may involve leaving an area deemed safe by the elder's caregiver. In the latter case, elders may be unaware of where they are, how they got there, or how to return. Elders have been observed to wander into street traffic or secluded areas and not be cognizant of the danger involved. Quite often this behavior presents a problem that relatives find extremely distressful and it is one of the major causes for institutionalization of the elderly (Chenoweth et al., 1986; Hiatt, 1985).

Estimates of the incidence of wandering behavior in institutions range from as low as 6% to as high as 18% (Rouse et al., 1986; Fennelly, 1985, Hiatt, 1985; Snyder et al., 1978). Based on these estimates between 85,667 and 257,000 individuals currently exhibit wandering behavior in the United States. Fennelly (1985) estimated the annual cost for staff hours spent surveilling wanderers is significant (cited in Rouse et al, 1986). For example, in nursing home facilities in Maine the cost of staff time amounted to $2,500 per wanderer. The financial burden on the relatives of wanderers is much greater since exhibition of wandering behavior typically leads to earlier nursing home placement and hence increases long-term care costs (Hiatt, 1985; Mace & Rabins, 1981).

Dementia with accompanying memory loss is probably the most frequently cited cause of wandering. In the majority of cases, dementia is caused either by brain degeneration from neurological disease (e.g. Alzheimers or Pick's) or by some form of cerebrovascular disease. As degenerative brain diseases run their course, disorders of attention and memory emerge as well as an impaired capacity to initiate, plan, or execute complex sequences of behavior. Theoretically, any one of these impairments may lead to orientation or behavioral problems which, in turn, could produce wandering behaviors.

Though wandering is frequently referred to as a complex behavior, interventions described in the literature are rather unsophisticated. Intervention typically includes physical or chemical restraint of the individual and/or caregiver monitoring of the wanderer's location in the environment to prevent elopement. Restraint includes placing wanderers in beanbag chairs, Geri-chairs, or tying an individual to a chair or bed. While restraint is common, its use raises ethical questions and may be physically or psychologically harmful to the wanderer. For those persons who have been tied down, restrained or confined to a room, high-tech solutions (surveillance) offer the person more freedom to move about.

However, the wanderer surveillance devices currently on the market do not provide the wanderers with feedback which may help them to become oriented in their environment or provide them cues that they have entered into unsafe areas. Rarely is training used to modify the individual's wandering behavior. A device in combination with an appropriate training intervention has merit because it may reduce caregiver responsibility for managing wanderers, and has greater ethical appeal than more restrictive types of treatment.

In a behavioral approach to treatment, cueing and reinforcement are used to increase the frequency of appropriate behaviors and extinction to decrease inappropriate behaviors. These techniques have been successfully used in long-term residential settings by Hussian (1981) and with the mentally ill elderly by Patterson et al. (1982). McEvoy & Patterson (1986) used specific training modules to teach skills needed for independent living to 15 demented elderly residents. The most dramatic improvement observed in the demented elderly was in spatial orientation (wayfinding), defined as the ability to find landmarks within the residential setting (i.e.,bedroom, cafeteria, etc.): "Improvement appeared to be more likely when physical practice was a large part of the training, when feedback was received from many sensory systems, and when less cogntive involvement was required. ...while cognitive abilities may not improve in this group, physical behaviors may be remediable, at least for some length of time." (p. 478)

Only one report exists in the literature of a behavioral intervention applied to a wanderer with the intent of modifying her wandering behavior (Donat, 1984). However, it is flawed methodologically, being a case study without the use of a reversal technique, and for that matter, with an intervention that can only be loosely defined as a behavioral technique. The subject was a 79 year old woman who had been involuntarily committed to a geriatric treatment center because her family could no longer abide her tendency to wander off. While in the residential setting, she frequently wandered into other patients rooms which greatly disturbed the other residents. One week of baseline measurement indicated she wandered into other residents room at a rate of 16 intrusions per hour. The author observed that she tended to either look out the windows or into a dresser mirror of the rooms she entered; neither of which she had in her own room. The intervention tried with her was to move her to a "room with two views," for herself (mirror) and of the outside (window). Her intrusions into others' rooms decreased from the 16 intrusions/hr to less than 2/hr. The rate was maintained at 1-month and 4-month assessments. No further intervention was tried. This case study illustrates the importance of keen observation during the baseline measurement period, but beyond that, fails to advance beyond a common sense approach to treatment.

We hypothesized that a device which delivers a simple verbal command to return to a safe area might be effective in cases where wanderers are confused about their location or inattentive to the significant landmarks within the environment which conote safety. The success of this approach relies upon each elder's capability to process verbal feedback. In some elders the ability to attend to such information has been compromised by progressive brain deterioration.

Past research has shown that the use of an annoying sound can be effective in the reduction of blindisms in children with minimal or no residual vision (Blasch, 1978). We believed that this method could also be effective for elders whose wandering behavior was unaffected by the presentation of verbal feedback. Certain scraping sounds, i.e., fingernails scraping on a blackboard, appear to have an inherent capability to arouse attention and avoidance behavior. Interestingly, contrary to common belief, it is not the high frequencies which lead to the judgements that the sound is aversive but the mid to low frequency band tones. Furthermore, the amplitude of the wave is not a significant factor (Halpern et al., 1986).

Either procedure outlined above could have the desired outcome of reducing or restricting wandering behavior. The latter procedure is more "intrusive" than the former and may not be necessary in all cases. We used an A-B-A-B reversal technique embedded in an additive component behavioral design to prevent "over kill" in the application of the interventions. Those elders whose wandering behavior became under the control of the voice stimulus were not subjected to the aversive stimulus.

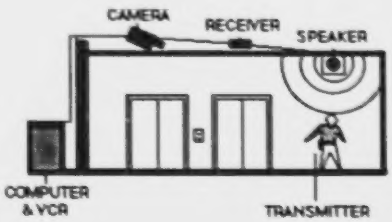
Method

Subjects

We studied nine elderly male nursing home patients identified by nursing staff as wanderers based upon their frequent encroachment of areas deemed to be unsafe by their caregivers. The mean age of the subjects was 82.8 years. All patients had received a medical diagnosis of senile dementia, with the exception of two patients diagnosed as having had cardiovascular accidents (CVA). The procedure for all subjects in this study was approved by the Emory University Human Studies Committee.

Apparatus

A research instrumentation package (CPT) was developed to serve as an integrated data collection device in measuring a stimulus/response effect. The CPT was designed to objectively record wandering behavior and establish the parameters of a feedback/alert device for wanderers. The CPT consists of several independent pieces of equipment connected together by a central control unit (IBM PC).

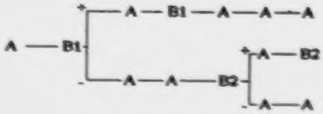


The electronic detector developed as part of the CPT is a short-range Pulse Code Modulated (PCM) radio frequency transmitter. Although each transmitter has the same carrier frequency, it can be set to send its own PCM "code," so that each subject can be identified. The transmitter is small and unobtrusive (5"x1"x0.5") and is attached to the wanderer's belt or clipped into his front shirt pocket. The receiver is tuned to the carrier frequency of all the transmitters, and has discriminators to "decode" each transmitter (a relatively simple digital circuit). The receiver contains a micro–processor circuit to allow control of several external functions. In the CPT, these external functions are: A videotape recorder and video camera; a digital voice playback (for selected messages and the aversive stimulus); and a variable time delay circuit. The microprocessor in the receiver has an RS-232 input/output line to allow the receivers to be interconnected. The receiver operates from an A.C. powered D.C. convertor, and is in a package that is easily mounted in the suspended ceilings (6"x4"x2").

Procedure

All subjects were evaluated with regard to background information and selected based on an evaluation of their wandering behavior as reported by the nursing staff. Then for a period of one week, the behavior of inpatient subjects was videotaped (CPT) without being exposed to the study interventions (Baseline).

Three locations defined as off-limits to the subjects were monitored at the inpatient settings at the VAMC. Two conditions of stimulus presentation were considered: voice output (B1) and an aversive auditory stimulus (B2). The technical equipment, as described above, allowed the voice output or aversive tone to be applied in selected locations. Each subject was exposed to the voice stimulus (B1) condition during week 2. Subjects whose frequency of encroachments were reduced by 75% or more were returned to baseline (A) during week 3, readministered (B1) in week 4, and reversed to baseline for the remainder of the experiment. Thus, they had been exposed to a complete A-B-A-B reversal technique, in which A represented the absence of the stimulus condition and B, the presence of the stimulus condition, allowing a functional evaluation of the effect of the voice intervention on their wandering behavior. Subjects in which B1 did not reduce their wandering behavior to criterion were returned to baseline during week 3-4 and then exposed to the aversive tone (B2) during week 5. Again, subjects whose frequency of encroachments were reduced to criterion, were returned to baseline in week 6, and exposed to B2 during week 7. The subjects who did not reach criterion during week 5 were returned to the baseline condition (A) for the rest of the experiment. Here again, a complete A-B-A-B reversal technique was administered to those subjects who reduced their frequency of encroachments. See figure below.



A = NO TREATMENT
B1 = VOICE
B2 = SCRAPE

The behavior of the subjects was evaluated from video tape independently by two trained observers. They coded a variety of behaviors using a behavioral mapping scheme adapted from Linsk & Miller (1986) which had been used to evaluate the impact of an Alzheimer's disease family care unit, as well as, encroachments into caregiver restricted areas, elopements, and the patient's behavioral reactions to the stimulus conditions. The percentage agreement between raters was obtained and analyzed.

Results and Conclusions

Results and the conclusions we have drawn from them will be presented at the RESNA '87 10th Annual Conference.

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GUIDE TO GERONTOLOGY INFORMATION AND FUNDING RESOURCES

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Consultant Rehabilitation and Special Education Technology

ABSTRACT:
Researchers in the field of gerontology face a growing number of resources for both information and funding as the field expands, yet some researchers are unaware of many of these. This paper describes several existing information resources, including those dedicated to gerontology and those which have some gerontology information in them, and which are publicly accessible or only privately accessible. The paper also describes some information clearinghouses which are in the planning stages. Brief descriptions of the federal agencies and private foundations which fund gerontological research are also included.

At the time of writing, neither a single comprehensive electronic database on research on aging, nor a single source of information about sources for funding for research on aging exist. As a result, the search for this information can be both frustrating and time consuming for the researcher in this field. An additional problem is that although researchers may keep current with publications in their specific field, many researchers do not publish the results of their research projects, and so their information is not accessible.

The problem is exacerbated by the fact that the future of federal and state funding, though fairly healthy at this point in time, is uncertain. The largest number of projects and the greatest amount of money in this area is presently provided by foundations.

INFORMATION

Several large publicly accessible electronic databases are either dedicated to, or include information about aging. They include:

AgeLine which is funded and operated by the American Association of Retired Persons (AARP), is a bibliographic database. It includes descriptions of research on aging which was funded by the Administration on Aging from 1976 to 1980, as well as abstracts of journal articles, books, government documents, dissertations, and conference papers in the area of aging . The focus of the database is the social psychological aspects of aging. The orientation of the database is toward consumers. It is publicly accessible through BRS.

AGING AND DEVELOPMENTAL DISABILITIES INFORMATION EXCHANGE which is sponsored by the Center on Aging at the University of Maryland. It provides bibliographic information as well as listings of other information sources in the field, and upcoming conferences and meetings. It is accessible to the public.

CRISP (Computerized Retrieval of Information on Scientific Projects) which is funded and operated by the National Institutes of Health. It is continuously updated to include information related to research funded by the National Institutes of Health, and the Department of Health and Human Services. Although it cannot be accessed and searched directly on-line by the public, requests for information in writing or by telephone are honored. It has several aging-related descriptors in its thesaurus.

HNRIM (Human Nutrition Research and Information Management Database) which provides abstracts on human nutrition research and training activities which are funded by the Federal government. It is updated quarterly and is available to the public through the National Technical Information Service (NTIS). It includes descriptions of several projects which address issues related to the elderly.

IRRIS (Interagency Rehabilitation Research Information System Database) which is funded and operated by the NIHR. It is a computerized inventory of abstracts of rehabilitation research funded by more than 30 Federal agencies. The database is available on-line through BRS (where it is called IRRI), and can be searched using several gerontology-related descriptors.

NARIC (National Rehabilitation Information Center) which is funded by the NIHR and operated by the Catholic University of America, has abstracts and descriptions of research, reports, fugitive documents in the field of rehabilitation. Their thesaurus includes descriptors in aging. It is accessible through BRS.

NATIONAL ARCHIVE OF COMPUTERIZED DATA ON AGING which is operated by the Inter-University Consortium for Political and Social Research at the University of

Michigan at Ann Arbor. It includes data sets of statistics in the field of aging. It is available through the SPIRES information retrieval system.

MEDLARS (Medical Literature and Retrieval System) is operated by the National Library of Medicine (NLM). It includes more than 20 individual databases which are all related in some way to medicine. Several of these databases have information related to on aging. It is available directly on-line and at more than 1900 institutions which subscribe to it, and through the BRS and DIALOG database vendors. Additional information is available from 1-800-638-8480.

It is important to note that each of these databases has developed its own thesaurus, therefore thesaurus descriptors appropriate for one database, may not be appropriate for another. It is also important to remember that each of these databases was developed with different purposes in mind.

In addition to these databases, individual federal agencies will provide information about the projects they have funded. Generally this information includes a brief abstract, the amount of funding, the funding period, the name of the principal investigator and his/her affiliation. This is usually available in the form of a published report from individual agencies. Publication of these reports may be quarterly, semi-annually, or annually, depending on the individual agency. At the present time, most agencies funding research in aging are putting this information into electronic form, and it may be possible, depending on the system used by each individual agency for it to be searched. Of the 25 agencies who are participants in the Interagency Committee on Research on Aging, none have systems which are publicly accessible at the present time.

Another source of information about which agencies are funding research on aging, and the kinds of research they are funding, is the annual report compiled by the Senate Committee on Aging, entitled Developments in Aging. It comprises three volumes: Volume I describes aging-related activities Congress has been involved in over the past year including proposed and passed legislation, and policy development; Volume II describes the aging related activities Federal agencies have been involved with over the past year; and Volume III describes demographic analyses and statistical reports in the field of aging.

FUNDING

There are about 25 federal agencies which fund research in aging and are members of an Interagency Committee on Aging, which meets regularly and is chaired by Ms. Shirley Bagley (Director of Special Projects, National Institute on Aging, 9000 Rockville Pike, Room 2C06, Bethesda, MD 20814). This Committee exchanges information and coordinates activities related to research on aging. Detailed information about what each agency has funded, funding restrictions and requirements, and funding schedules, each agency must be contacted individually.

Many states also fund research in aging, usually under the aegis of a Department of Economic Security or the equivalent.

Foundations dedicated to funding research in the area of aging have formed an informal network or consortium called Grantmakers in Aging which meets from time to time to discuss common issues and share information. A publication, Grant Making for the Elderly, prepared by the Florence D. Burden Foundation, and distributed by the Foundation Center, 79 5th Avenue, New York, New York, 10003 for $6.50 + $2 postage and handling provides results of a survey of foundations which fund research in this field. For brief descriptions of each project funded by an foundation, the goals of the foundation, and the restrictions, requirements, and funding schedule of the foundation, the information can be found at The Foundation Center, 79-5th Avenue, New York, NY 10003 (212) 620-4230, or one of collections of Foundation Center materials which can be found in several locations nationally. For more detailed information, each foundation must be contacted individually. Foundations often have specific geographic and demographic restrictions about what they will fund.

TRENDS

Several trends are likely to develop as the research base in aging broadens:

- a single comprehensive electronic database on research in aging may be developed sometime in the future if a demand for such a database exists, the NIA's Interagency Committee on Aging funded a project in late 1986 to determine the feasibility of establishing such a database
- a database of researchers in the field of aging may be developed by the American Psychological Association in the future
- more Federal interagency funding of projects including:
    - a) joint funding of projects
    - b) funding of different phases of projects
- more rigorous review of proposals to determine whether a very similar project has been funded previously by either that agency, or another agency or foundation
- increase in the number of different projects being funded

- increase in the kinds of projects being funded
- increase in the amount of money available for funding
- increase in the linkages and cooperation between foundations
- increase in the linkages and cooperation between agencies
- increase in the linkages and cooperation between foundations and agencies

GUIDELINES FOR GETTING FUNDING

To obtain funding, researchers must expand their horizons, and look beyond the traditional sources they have used. Foundations and corporations are generally underused sources for funding, yet they have money available. For additional information about these and other funding resources, see the Resources Section by Frederica Bowden and in the publication Clinical Advances in Rehabilitation, Eisenberg, M. et al, Springer Publications, NY (in press).

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TRIAL OF FOAM SEAT CUSHIONS USED FOR THE PREVENTION OF DECUBITUS ULCERS IN THE ELDERLY

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ABSTRACT

Foam cushions in the slab or contoured form are commonly placed in the wheelchairs of elderly chronically ill persons for the control of pressure to prevent decubitus ulcers (DU). During a five month period, 52 elderly patients in an extended care facility were randomly assigned to sit on slab (N=26) or contoured (N=26) cushions. Seventy one percent developed a total of 72 DUs. No significant differences were found between groups in the proportion who developed DUs, and in the incidence, location, severity or duration of healing of their DUs. Most DUs occurred over the ischial tuberosities and in skin areas associated with soiling in the incontinent patients. Expensive customization of foam cushions needs to be justified.

INTRODUCTION

A common approach to the prevention of decubitus ulcers (DU) in elderly persons is aimed at the reduction of excessive pressure in seating. The control is offered by placing a standard shape slab of polyurethane foam cushion over the wheelchair seat to distribute pressure; or by contouring the foam, customized for the individual user, to reduce pressure in the region of boney prominences.

Little is known of the relative clinical efficacy of these two methods of pressure control. A number of studies have examined seat cushions or cushion covers for their features related to DU prevention. However the results can not be generalized to elderly patients because of their research design limitaitons; e.g. use of small samples of young normal or spinal cord injured persons and taking static measures of pressure with instruments of unknown reliability that alter compliance (1-5). It should be noted that older persons exhibit a larger variation in pressure reaction during sitting, suffer greater occlusion at a given value of pressure, and experience three times the shear in their sitting mechanics (6).

METHODS

In a modified sequential clinical trial we studied the incidence, location, severity and healing duration of DUs that developed in 52 consenting patients over the age of 60 years who sat for three or more hours daily for a period of 5 months in their wheelchairs using a slab (N=26) or a contoured cushion (N=26). They were selected based on carefully defined criteria and were given equal rehabilitation, nursing, nutrition and medical care under the standard protocol of the extended care facility in which they resided.

The contoured cushions were customized according to the recommendations of Peterson and Adkins (7). However they were modified to include: a 5 cm deep cut in the posterior aspect extending 2.5 cm anteriorly and laterally to accommodate the ischial tuberosities, and a 3.8 cm thick ischial bar glued to the cushion anterior to the ischial cut out (Fig. 1). All cushions were provided with a polyster knit cover laminated on the inside and were mounted on a 0.6 cm plywood platform. Appropriate wheelchair adjustments and periodic examination of seating were conducted by a seating expert for all subjects.

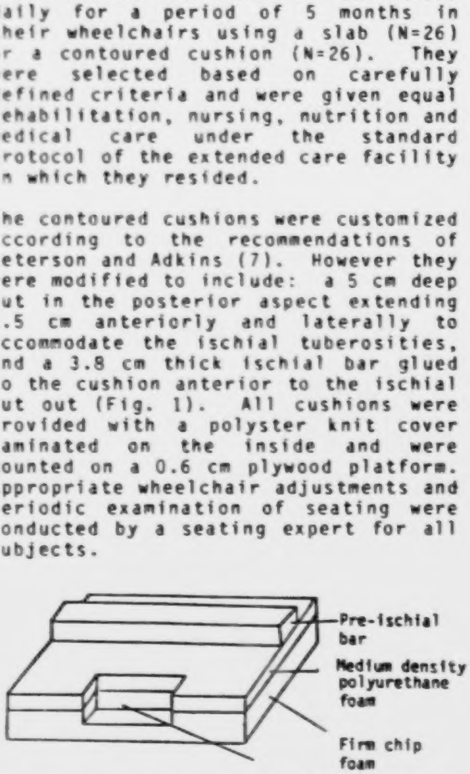

Fig. 1. Contoured Foam Cushion

During the trial weekly skin checks were conducted for the incidence, location, severity, and healing status of any DUs in the subjects. Severity was measured by the Exton-Smith Scale (8) which is recorded in grades of 0 = none, 1 = persistent erythema, 2 = localized blister, 3 = superficial sore, 4 = deep sore, 5 = extensive gangrenous sore.

RESULTS

No significant differences were found between the two groups of subjects on the basis of chi-square or t-test with respect to sex, age, weight, Norton's score of DU risk (9), previous incidence of DU, primary diagnoses, sensory status, presence of friction, time in wheelchair, or mobility status.

Seventeen patients in the slab group and 18 in the contoured group developed 35 and 37 DUs respectively. No significant differences were found by the chi-square test in the proportion of patients who developed DUs or in the incidence and locations of DUs in the two groups. Thirty four percent of all DUs developed in the area of ischial tuberosities while another 30% occurred in the buttocks and thighs associated with soiling in the incontinent patients.

None of the sores reached level 4 or 5 in the Exton-Smith Scale. They were mostly (60%) contained in level 1 (persistent erythema) and were healed in an average of 6 to 8 weeks. The results of t-test did not yield significant differences between the slab and contoured groups with respect to severity or healing time of DUs.

DISCUSSION AND CONCLUSION

The professionals who are concerned with the well being of elderly patients face a dilemma in choosing a common and basic piece of equipment, a wheelchair cushion. They can offer the individual an inexpensive slab of foam or a custom contoured version which would require the services of a therpaist who is a seating expert. Based on our limited observations, and in the absence of other evidence, contouring of cushions does not appear to be justified. Health care professionals should consider DU prevention by examining the hygiene of the incontinent elderly persons as well as offering mechanical alterations for pressure control.

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A STUDY OF FALLS BY THE ELDERLY

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ABSTRACT

This paper briefly reviews several studies of falls on stairs and of the vulnerability of older persons to certain kinds of visual deceptions and distractions. It concludes with the observation that many falls by the elderly may be coincident with abrupt changes in environmental conditions.

INTRODUCTION

Using data on the frequency and severity of product-related injuries treated at a sample of hospital emergency rooms, the Consumer Product Safety Commission estimates that there were 1,203,041 injuries resulting from stair accidents in 1982. This is a rate of 531 for every 100,000 Americans. Almost 4,000 victims of stair accidents die as a result of their injuries each year. Estimates based in part on data compiled through the National Electronic Injury Surveillance System (NEISS) indicate that one in seven persons will at some time in their life have a stair accident resulting in injuries severe enough to require hospital treatment (1).

Although the NEISS data indicate that the elderly have fewer stair accidents per capita than people in other age groups, the severity of the injuries sustained by the aged is quite high. Over 85% of all the deaths attributed to stair accidents occur to people over the age of 65. However, the problems encountered by the elderly on stairs may be more serious than these figures indicate.

In a survey of routine stair use in Milwaukee, it was found that people over 65 use stairs much less frequently than younger adults (3). Adjusting the frequency figures to account for these findings reveals that people over 65 have far more accidents per encounter than any other age group. In fact, their apparent avoidance of stairs may be attributable to a sense of their own vulnerability. It has also been noted that many older people die of pneumonia following hospitalization for injuries sustained in stair accidents and that a full accounting of such deaths could more than double the nearly 4,000 fatalities attributed to stair accidents each year.

FALLS ON STAIRS

A major study of stair accidents involved the videotaping of approximately 32,000 stair users in a variety of public settings. Twelve stair accidents and over 120 obvious missteps were recorded on these tapes. This made it possible to compare the behavior of persons who had an accident or misstep on a specific light with a matched sample of persons who had used the same flight without incident (3).

As a result of this analysis it was clearly established that making a successful transition from walking on a level landing to walking down a flight of stairs requires that people first look directly at the stair as they approach and step onto it, and then cautiously get the feel of the treads kinesthetically as they descend the first two or three steps. In this manner individuals visually estimate the most appropriate place to put their foot on the first tread, and then confirm the accuracy of both their estimates and their initial foot placement through skeletal-muscular feedback. This whole process was interpreted as an integrated visual and kinesthetic "test" of the prevailing conditions on the stair and of one's response to those conditions (3).

According to this interpretation, stair accidents occur either when some portion of the essential testing process is disrupted, or when users encounter a nonconforming condition which prior visual and kinesthetic feedback had led them not to anticipate--such as a tread that is slightly out of position. When these kinds of hazards occur near the top of a flight, users are more likely to notice and compensate for them because they are more actively attending to the stair at this point. However, when unexpected conditions are abruptly encountered in the middle of a flight, a user is quite vulnerable to having a serious accident because he or she is likely to be attending to something other than the stair at this point. In effect, the user's awareness of a hazardous condition is as critical to successful stair use as the hazard itself.

The most important piece of visual information needed to successfully negotiate stairs is a singular and unambiguous indication of the position of the edge of each tread when the flight is viewed from the top landing. A major impediment to the accurate detection of tread edges exists if optical illusions or visual noise occur near some or all of the nosings in a given flight. For example, vivid patterns in carpeting can often overpower the user's ability to detect tread edges. This is because the edges created by contrast within the pattern compete with the visual cues indicating the edge of each tread.

Splotchy patterns created by terrazzo or a shag carpet, can also camouflage the tread edges. Here the random array of multi-colored stones or the tangle of fibers can trigger visual fusion across the nosings such that adjacent treads give the illusion of a continuous surface. Whenever a vivid, repetitive, or random pattern is used on stair treads an unstable figure-ground relationship can be established which confounds the user's ability to detect the edge of each tread (3).

In order to accommodate the visual (and kinesthetic) testing that seems to be an essential factor in successful stair use, it is important that a complete, correct, and consistent pattern of visual cues be provided in a manner that accentuates and corresponds with conditions actually prevailing upon the stair. This means that all colors, edges, lines, alignments, patterns, and textures must interact to produce a "true" representation of the extent, position, and condition of each of the separate treads (3).

VULNERABILITY OF THE ELDERLY

Most of the serious injuries resulting from stair accidents among the elderly, as well as other age groups, occur in descent. Typically the leading foot oversteps a tread and "slips" over the nosing while the trailing leg collapses under the body. With the weight of the body falling on either the collapsed leg or the stair itself, typical injuries include fractures of the lower leg or hip or sprains to the lower back as forward momentum carries the falling body further down the stair.

The few studies of stair use and stair accidents that have focused primarily on the elderly give a strong indication that vision may be a major factor in their heightened vulnerability. Sheldon (6) found that 63 out of 171 falls among old people resulted from stair accidents. The most frequently cited cause cited was "missing the last step or last group of steps in the mistaken belief that the bottom has been reached". This accounted for 15 of the accidents, followed by poor illumination which accounted for 13 accidents.

In studies reported by Pastalan (4) subjects wearing glasses that simulated visual capabilities typically found among people in their late seventies reported considerable difficulty in discriminating "risers and treads while going down a flight of stairs, particularly when the stairs were carpeted with a floral print carpet." He concluded that due to developmental (not pathological) changes in the lens of the eye, the elderly often experience a great deal of difficulty negotiating flights of stairs.

In a formal pilot study which used Pastalan's glasses to simulate the effects of aging eyes, Archea, et al. (3) found that younger subjects took almost twice as long to descend the first riser of a flight of terrazzo stairs when they wore the experimental glasses than when they did not. They attributed this difference to the increased time required to detect the edge of the tread when vision was experimentally impaired. These findings suggest that much of the decline in stair performance found among older persons can be attributed to changes in visual performance.

The following scenario illustrates the problems encountered by the elderly stair user: "when descending a flight of stairs, a fully sighted person can usually see where to place his feet. However, because a person with diminished capability may not be able to judge the extent of the tread below, he may not be sure that his foot will have a firm footing until he has actually made contact. Unfortunately, when descending a stair, people generally have to release the support provided by their trailing leg (the one on the higher step) before their leading leg makes contact with the tread below. Therefore older people and other persons with visual impairments encounter an interval of time during each step when they can neither support their weight on the tread above nor be assured that their weight will be supported on the tread below. Furthermore, the duration of this interval increases as the speed of movement decreases (which occurs as a person becomes less sure of his next foothold). As a result of this precarious situation, persons with difficulties judging the extent of the treads below may have to hold onto the handrail, almost as it it were a "third leg" (3)."

Overall, these studies suggest that there are strong interactions between the visual capabilities of older persons, the visual qualities of stair treads and other parts of the stair environment, and the performance of older people on stairs. These interactions also characterize the older person's vulnerability to stair accidents and to the subsequent injuries that inevitably are associated with them.

ABRUPT ENVIRONMENTAL TRANSITIONS

Much of the recent bio-medical research on falls among the elderly has focused exclusively on the precipitating characteristics of the population at risk (e.g. progressive osteoporosis, postural hypotension and postural sway). However, it is obvious that falls and resulting injuries do not occur randomly among the population characterized by these vulnerabilities. It seems far more likely that such falls are coincident with attributes of environments or situations that exacerbate the pre-existing vulnerabilities of individuals.

For example, many stair accidents were attributed to architecturally triggered human errors at points of abrupt environmental transition (3). These are points at which the perceptual or performance capabilities of a person are momentarily taxed beyond their limits, resulting in some combination of uncertainty, distraction, hesitation, over-extension, or loss of motor control.

Many falls that occur "for no apparent reason" may be linked to points of abrupt environmental change. Candidates include major changes in the slip-resistance of walking surfaces (including moisture) (5), sudden increases or decreases in ambient temperature (including entries and vestibules), and points requiring rapid accommodations to shifts in ambient light levels (including shadows and glare).

Another candidate is a location-specific distraction (2). Consider the following report of an actual fall by a 79 year old woman at the intersection of two hallways in a nursing home:

> ...the victim approached the corner, holding onto the railing which runs along the right and left sides of the entire single story nursing home. She further noted the victim slipped *for no apparent reason* as there were no obsticles (sic) in the area. As she fell, she struck her forehead on the sharp corner of the railing. (Emphasis added.)

Although this incident was reported to have occured "for no apparent reason", it is plausible that a sudden turn of the head to scrutinize a compelling scene that had just come into view around the corner could have triggered syncope in conjunction with orthostatic hypotension. The precise role that such points of spatial or environmental transition play in falls by the elderly demands to be investigated.

ACKNOWLEDGEMENT

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REHABILITATION TECHNOLOGY AND DESIGN FOR THE ELDERLY: A GERONTOLOGIST'S PERSPECTIVE

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ABSTRACT

This presentation will focus on normal age-related changes in the sensory, cognitive and social systems of elderly adults which may affect technological design for this age group. A description of specific age-related changes in the visual and auditory systems and their implications for rehabilitation design will be presented. A discussion of age-related changes in older adults' ability to process information will then be discussed, with an emphasis on modes of presenting information that might be particularly effective for this group. Finally, rehabilitation specialists must also be aware of the unique demographic and social characteristics of an elderly population to design effectively for them.

OVERVIEW

The rehabilitation needs of the elderly are substantial. It is estimated that 20% of indidividuals aged 70 or older require help in daily living, and that figure rises to 40% for those individuals over age 80 (1). The rehabilitation needs of the elderly will continue to rise since the aged population is growing rapidly due to falling birthrates and increased mortality rates, with the 80+ segment of our society increasing the most (2). Rehabilitation specialists need to be sensitive to certain general age-related changes that characterize elderly individuals in order to design maximally effective intervention strategies and technologies for the aged.

SENSORY CHANGES

The Visual System. There are a number of pronounced changes in the visual system that are concomitants of normal aging and have specific implications for rehabilitation strategies. First, the ability to focus on both near and far objects declines measurably with age, particularly after age 70 (3). Second, older adults have smaller pupils, so that less light can reach the retina, resulting in a need for high levels of illumination (4). However, clouding and yellowing of the lens which accompanies aging scatters light, resulting in sensitivity to glare under conditions of high illumination in the elderly, so particular attention to lighting is essential for optimal viewing conditions (5). Due to the yellowing of the lens, older adults also have difficulty discriminating colors, particularly blues, blue-greens and violets (6). Finally, there is a marked reduction in contrast sensitivity in the aged, so that difficulties are experienced with any visual stimuli where contrast among boundaries is low.

The implications of these findings with respect to rehabilitation design for the elderly are straightforward. First, displays need to be well-lit, glare should be minimized, and contrast between figure and ground must be high. Devices or interventions which rely upon color-coding and/or fine visual discrminations will not be useful to older adults, a result which was confirmed in a direct comparison of young and elderly adult's ability to remember color (7). Large characters which accomodate to declining visual acuity along with high figure-ground contrast will be most useful.

The Auditory System. Older adults also show age-related decline in the auditory modality, with a pronounced loss for high-pitched tones, a condition known as presbycusis (8). Presbycusis is more pronounced for aged males than females (9). Thus, rehabilitation specialists should be aware that, because of presbycusis, older adults generally find a male voice easier to understand than a female's, since the male will produce fewer high frequency sounds. It is also important to recognize that levels of volume which are comfortable for young adults may be unintelligible for the elderly.

COGNITIVE CHANGES

Age-related Slowing. Perhaps the most reliable finding in the psychological literature with respect to elderly adults is that they tend to take measurably longer periods of times to perform virtually any type of task, from a simple reaction time measure to a complex decision-making task. In fact, Salthouse has proposed that age-related slowing results in a general behavior decrement and is thus responsible for most observed age-related declines in behavior (10, 11). Salthouse has also pointed out that older adults' performance becomes most divergent from that of young adults when task difficulty increases. That is, there is an age x complexity interaction where older adults' performance differs most from young adults on very complex or difficult tasks (12).

The implications of these findings for rehabilitation design and intervention are straightforward. First, it is essential that rapid choices, decisions or movements not be required of the elderly adult. Whenever possible, interventions should involve self-pacing rather than have timing generated by a device or the caregiver. There are a number of studies in the psychological literature which indicate that performance decrements between old and young are frequently small or nonexistent when pacing is controlled by the subject (13, 14). Second, it is important that devices or programs not be unduly complex, as older adults will have particular difficulties in this area. A device or display of some complexity that is readily mastered by a young adult may prove to be difficult for the elderly, so it is essential to pilot interventions on the targeted population.

Memory. There are innumerable laboratory studies which indicate that older adults show memory declines compared to young adults in comparable memory situations. Contemporary memory research has focused on determining with which aspects of the memory situation older adults have difficulty and what specific age-related changes in memory occur. From the point of view of the rehabilitation specialist, it would appear to be at least as important to ask what aspects of the older adult's memory shows the least decline, and use this information to enhance the rehabilitation process. Research in my own laboratory has indicated that older adults have exceptionally good picture memory and that age-related decline in the ability to recognize pictures is small or nonexistent (15, 16, 17). Thus, these findings suggest that older adults will find it easier to remember and process information presented pictorially rather than verbally. Additionally, we have found in our laboratory that older adults find spatial location information very easy to remember and will remember this information well above chance levels, even when not instructed to study it (18, 19). Thus, it would make sense to capitalize on the fact that spatial information is readily acquired by the elderly and design devices and environments with spatially distinct components, as appropriate, to enhance memory support for the elderly.

Other research indicates older adults have difficulty organizing information that they need to remember. One area where organization is critical is in the area of medication compliance. Older adults taking multiple medications must organize a complex drug regimen across a 24-hour period. To assist the elderly in this task, we are investigating the role of organizing this information for them on a drug wheel with visually-displayed instructions. We are also examining more efficacious ways of designing prescription labels that interface better with the aged adult's cognitive system. The use of pictorial instructions as well as well-defined organizational strategies are of particular interest in this area (20). In general, research suggests that information should be presented in a stereotyped, straightforward fashion so that older adults donot have to reorganize it themselves in order to use it.

I would also like to interject a word of caution here. Although older adults do show measurable memory decline in the laboratory, I do not wish to imply that they have extraordinarily poor memories. On the contrary, their memories appear to function quite appropriately and adequately for familier activities of daily living, and they are quite capable of understanding complex material when presented appropriately. I do think it is as serious a mistake to assume that the elderly individual is substantially compromised at the cognitive level as it is to assume that no age-related cognitive changes occur.

Intelligence. No discussion of the aged adult's cognitive system would be complete without addressing the issue of age-related changes in intelligence. A great deal of data on this issue, both cross-sectional and longitudinal, exists. The findings with respect to age-related declines in intelligence are sufficiently regular that they have been referred to as "the classic aging pattern" (20). This pattern is described by age-related declines on performance measures of intelligence such as Block Design, Digit-Symbol Substitution and Picture Arrangement. These are typically viewed as measures of ability to deal with novel and abstract materials and also are highly speeded behaviors. There is little or no decline on measures of verbal intelligence across the lifespan. Vocabulary tasks, General Information and Comprehension are examples of subtests in this area and reflect general knowledge acquired over the years. With respect to rehabilitation technology, these findings suggest that elderly adults have rich vocabulary skills upon which to draw, but again might have some difficulty dealing with abstractions, novel situations, or as mentioned earlier, with devices that require speeded behaviors.

DEMOGRAPHIC AND SOCIAL CHARACTERISTICS OF THE ELDERLY

It is important to recognize that there are certain demographic and social trends that characterize the elderly which might impact on rehabilitation design and technology. First, women are heavily overrepresented in this population. The ratio of men to women is .8 in the 65 to 69 age group and decreases to .45 in the 85+ age group (21). Thus, it is more likely that elderly women will be users of services. Second, rehabilitation specialists must recognize that they cannot rely upon an elaborate family or social network when designing for the elderly, particularly for female clients. Of males over age 65, 78% live with spouses, whereas only 37% of females do. Furthermore, it is frequently the case that a very elderly person, if cared for at home, is assisted by a relatively frail elderly female who is 60+ herself. Thus, the highly committed, caring family network that is frequently available in the rehabilitation of younger adults occurs with much less frequency in an elderly population.

SUMMARY

It is apparent that gerontologists have a research perspective to offer rehabilitation specialists to assist them in their efforts to improve the quality of life of the aged adult. At the same time, it is important to recognize that this is a two-way street. Many of the problems with which gerontologists are grappling with respect to the needs of our aging population are issues that have been addressed in some fashion within a rehabilitation framework. Gerontologists, like myself, who venture into the field of rehabilitation are frequently struck by the applicability of many rehab ideas and innovations to the population of normal elderly. Cross-talk and cross-disciplinary discussions between gerontologists and specialists in rehabilitation would seem to yield substantial benefits for both disciplines.

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Author Index

Abbas, J., 603
Abraham, Jr., F.J., 571
Acimovic, R., 621
Adelstein, B.D., 829
Adkisson, J., 462
Agogino, A.M., 148
Aisen, M.L., 829
Albanese, M.K., 5
Alden, A., 454
Allison, J.D., 243, 317
Allsop, K.G., 225, 293
Alm, N., 127
Amerson, T., 419
Amundsen, L., 243
Anderson, L.L., 353
Andrellos, P., 745
Andrew, J.T., 225
Antczak, J.M., 539
Archea, J., 885
Armstrong, W., 207
Arnott, J.L., 106, 124, 127
Atkinson, C., 717
Axelson, P.W., 477
Aylor, J.H., 498, 504
Bailey, M.N., 861
Bajd, T., 645
Baker, B., 118, 154
Baker, E., 162
Baker, L.L., 651
Balfour, L., 697
Balsdon, G.J., 362
Barker, M.R., 148, 160
Barnes, K., 43
Barnicle, K., 603
Bass, D., 547
Baumhauer, J., 840
Baxter, M.F., 513
Baxter, T., 243
Beaupre, G.S., 826
Belbin, G., 213
Bellaire, K., 290
Benjuya, N., 252
Benko, H., 585, 645
Bentrup, J.A., 121
Bergstrand, J.L., 550
Bernett, J.M., 359
Bernstein, J., 103
Black, R.C., 338
Blackshear, L.A., 864
Blasch, B., 877
Bleck, E., 832
Bluj, A.M., 18
Bochmann, D., 213
Bolam, J.M., 331
Bollini, G., 832
Bondurant, M., 24
Boonzaier, D.A., 691
Boothroyd, A., 404, 425, 428, 734
Boubekker, M., 434
Boves, L., 115
Bowden, F.G., 880
Bowles, J., 697
Brabyn, J.A., 454
Brady, M., 49
Bresler, M.I., 183, 281, 544
Brown, G.A., 299
Brown, K.E., 536
Brubaker, C.E., 486, 559
Buckett, J.R., 660
Burnham, W., 79
Burns, S.D., 281
Campbell, J., 648, 657
Cannon, T.W., 562
Carley, D., 333
Carlson, F., 79
Carlson, G.S., 94, 103, 157, 162
Carlson, J.M., 5
Carlson, K.L., 823
Carroll, S.G., 618
Carter, D.R., 821, 826, 838
Casavant, D.A., 326
Casey, D., 210, 377
Cats-Baril, W.L., 21, 296
Cavalier, A.R., 232
Cederna, P.S., 642
Chang, G., 817
Childress, D.S., 320, 492
Chizeck, H., 600, 603
Chung, K.C., 269, 323, 515, 568
Clemans, D., 544
Coker, C.C., 365
Collins, S.R., 591, 597
Collins, T.J., 507
Conine, T.A., 883
Constable, D.J.E., 57
Cook, A.M., 37, 142
Coombs, F., 876, 877
Cooper, D., 573, 876
Corbett, C.R., 395
Coutts, R.D., 287
Couvier, W.D., 81
Crangle, C., 773
Crigler, B., 796
Cronk, S.R., 109
Cummins, K.L., 398
Cunningham, L., 811
Cwiekowski, M., 68
Damarin, S.K., 770
Davey, K., 547
Davis, D.J., 553
Davis, D.W., 254
Davis, G.M., 591, 594
Delgado, M., 168
Delp, S., 832
Deluca, C.J., 326
Demasco, P., 112, 688, 742, 745, 799
Dewees, J.A., 15
DiNello, A.M., 323
Dodds, R., 13
Dolman, L., 678
Domina, C., 68
Doolittle, E.P., 62
Drake, L.A., 720
Du, Q.Y., 603
Duimel, J.J., 781
Duluk, J., 443
Dumper, C., 737
Dunlap, B., 68, 331
Durfee, W.K., 624
Durlach, N.I., 395
Durre, K.P., 437, 448
Dvorak, D.V., 35
Edwards, B.G., 605
Edwards, C.M., 702
Edwards, D.M., 702
Efron, R., 401
Egert, R., 867
Ehrlich, M., 835
Eisele, M., 437
Ellinghan, C.T., 317
Ellis, G., 329
El-Nahass, B., 252

Elting, S.F., 861
Enders, A., 345, 847, 858
Engelretson, A.M., 392
Ensign, A.S., 870
Erwin, H., 8
Farris, D.S., 726
Felts, T., 100, 174, 180
Fernandez, J., 32
Field, D., 468, 471, 697
Field, W.E., 756, 765, 767
Fijan, R.S., 823
Filia, P., 287
Filip, K., 533
Fisher, S., 259
Fleming, B., 256, 278
Foulds, R., 115, 778, 806
French, J.J., 145
Fyhrie, D.P., 838
Gajjar, K.C., 729
Galyas, K., 97
Garber, S., 513
Genoese-Zerbi, F., 100, 180
Gerrey, W.A., 464
Getschow, C.O., 100, 177
Giavedoni, B., 213
Gilbert, M., 745, 778, 799, 802
Gilden, D., 422
Gilmore, L.D., 326
Gilstad, D.W., 359
Gines, D.J., 385
Glaser, R.M., 591, 594, 597
Glass, K., 259, 776
Glenn, A.M., 474, 579
Goodenough-Trepagnier, C.,
 100, 151, 174, 177, 180
Goodrich, G.L., 431, 443, 451
Goodwin, D.M., 489, 556
Gould, A., 835
Gouvier, W.D., 74, 76, 385
Graves, W.H., 462
Greelish, S.J., 190
Grey, T.L., 142
Grip, J., 290, 333
Gros, N., 621, 627
Gross, M.D., 642
Grosser, M., 675
Gupta, S.C., 591
Gurski, T., 477
Hale, Jr., P.N., 65, 81
Hall, K., 776
Hall, M.G., 856
Halleck, J., 685
Halper, A.H., 290
Hammel, J., 776
Hammer, G., 672
Hanin, L., 428
Hanks, S., 254
Harkins, J.E., 388
Harris, W.H., 823, 835
Harvill, Y., 459
Haugh, L.D., 21, 296
Hawthorne, D.L., 492
Hayter, G., 850
Hazard, P.R., 229
Hecox, K.E., 398
Hedman, G.E., 207, 565
Hefler, K., 43
Heiner, D.E., 870
Hennessey, A.M., 407
Hennies, D., 431, 433, 451, 459
Hentz, V.R., 639, 675
Herring, C.E., 720
Higashihara, T., 202
Hildebrandt, J.R., 362
Hill, S., 213, 249
Hobson, D.A., 8, 348, 480
Hodge, W.A., 809, 823, 835
Hogan, N., 193, 284
Holloway, K.J., 368, 694
Horgan, H.R., 597
Horstmann, H., 112, 742, 745
Horton, C.R., 71, 74, 76, 385
Hotchkiss, R., 759
Howe, J., 256, 278
Howell, R.D., 770
Hoyer, E.A., 26, 380
Hranchuk, K.B., 308
Hsi, S., 148
Huang, J.T.Y., 708
Hnath-Chisolm, T., 425
Humphress, G.B., 359, 853
Hurd, K., 207, 565
Hwang, J.Y., 407
Ignagni, A.R., 660
Ingalls, R.L., 15, 40
Inigo, R.M., 495, 536
Isaka, S., 287
Itoh, H., 202
Jablonski, E., 46
Jaeger, R., 608
Jagacinski, R.J., 492
Jandura, L., 100
Jaros, L.A., 714
Jarvis, S., 468, 471
Jefferson, R., 820
Johnson, B.W., 504
Johnson, M.W., 660
Johnston, K.M., 784
Jong, M.M.T., 26
Juni, J.E., 642
Junkmann, B.C., 501
Kaiser, J., 873
Kauzlarich, J.J., 501, 507
Kelly, G., 547
Kett, R.L., 524, 553, 642
Khang, G., 636
Khawam. B., 588
Kijowski, P.J., 446
Kim, K.S., 495
King, R., 333
Kirby, N.A., 145
Kleczewska, M., 94, 157, 162
Klein, L.J., 56
Klein-Koonin, J., 290
Kleviansky, M., 691
Kljajic, M., 621
Knight, L.W., 210, 377
Ko, W., 603
Kobetic, R., 618, 630
Koeneman, J.B., 374, 873
Koheil, R., 249
Kohlmeyer, K., 207
Kohn, J.G., 356
Kolar, K.A., 216
Kolenc, A., 585, 627
Korba, L.W., 338, 609
Korst, J.W., 353
Kovacs, G., 675
Kraat, A., 168
Krag, M.H., 314
Kralj, A., 608, 645
Krohe, J.G., 240, 261
Krouskop, T.A., 513, 740
Kwee, H.H., 781
Kynast, L., 331
Ladin, Z., 326
Laenger, Sr., C., 52
Langbein, W.E., 331
Langley, D.R., 26
Langton, A.J., 29, 365
Lasko-Harvill, A., 459, 477
Lau, M., 883

Lauer, N.L., 436
Law, D.F., Jr., 10
LeBlanc, M., 196, 204
Lee, C.C., 711, 750
Lee, H.S., 790
Lee, K.J., 553
Lees, D., 796
Leibowitz, L., 139
Leifer, L., 776, 787, 790, 796
Lepley, M.G., 317
Leslie, J.H., 240
Levine, S.H., 177
Levine, S.P., 524, 553, 642, 714
Levitt, H., 389, 407, 410, 413, 416
Lew, R.D., 616
Lewis, N., 864
Liang, L., 773
Lim, R., 883
Lim, S.H., 496
Loerch, G., 24
Long, J., 633
Lovas, M., 338
Luck, R., 669
Lue, K.K., 287
Luebben, A.J., 705, 762
Lundervold, D., 46
Mabry, F., 748
MacConnell, B., 459
MacKesy, J., 207
Madson, M.J., 252, 267
Magnano, S., 533
Malezic, M., 585, 621
Malzahn, D., 32
Mann, R.W., 246, 299, 809, 817, 823, 835
Mansour, J., 600
Marcrum, J., 510
Margolis, S.A., 216
Mariano, T.R., 624
Marqui, H., 333
Marshal, D., 675
Marsolais, E.B., 568, 600, 603, 606,
 611, 613, 618, 630
Martens, P., 806
Martin, G.W., 515
Martinez, J., 513
Martino-Saltzman, D., 877
Mathsen, D.V., 754
Maxfield, M.M., 74
Maxson, J.W., 462
McAuliffe, A.P., 336
McCaa, C., 462
McClenaghan. B.A., 249
McConnell, M.V.C., 396
McGinnis, S., 229
McGovern, R., 568
McGovern, T., 24, 306, 533
McGrew, G.W., 568
McKinley, J.L., 431, 443, 451
McLaurin, C.A., 323, 480, 515, 559
McNeal, D.R., 37, 651, 654
McNeal, L., 419, 877
McSheffrey, L., 338
Medford, D., 254
Meeks, S., 678
Mensing, L., 43
Merbitz, C., 290, 333
Miao, C.L., 603
Michalowski, S.J., 773, 793
Michaud, P., 24
Miklavcic, D., 627
Miller, C., 193
Miller, J., 235
Miller, N.R., 784
Mills, R., 62, 664, 680
Milner, M., 91, 213
Mineo, B.A., 232
Minneman, S.L., 177, 745, 799, 802
Moeinzadeh, M.H., 784
Mogil, S., 290
Moisey, V., 691
Monahan, L., 480, 571
Moore, W.W., 731
Moran, R., 213
Mroczek, K., 290, 333
Muccio, P., 600, 603, 613
Mueller, L., 235
Murnaghan, J.P., 338
Murphy, T.E., 219
Nakai, R.J., 654, 657
Nashburn, J., 440
Naumann, S., 717
Neen, D.J., 737
Nelson, C., 204
Nelson, J., 281
Nelson, P.J., 699
Neuman, A.C., 389, 410, 413
Newell, A.F., 124, 127, 171
Nguyen, K.D., 639
Nickels, V.L., 287
Nilsen, K., 71, 81
Norris, L., 130
Nwaobi, O.M., 254, 264, 272, 311, 329
Oeth, R.B., 705, 762
Okazzki, C., 249
Olson, W.A., 748
O'Neill, H., 302
Otten, P., 873
Ozer, M.N., 2, 11
Pancioli, A.M., 714
Park, D.C., 888
Park, G.C., 699
Park, H., 787
Parker, D.J., 199, 204
Parnes, P., 91
Patterson, R., 239, 243
Peckham. P.H., 603
Pereira, J.M., 600, 630
Perkash, I., 776
Peterson, P.M., 396
Pfrommer, M.C., 35
Pham, H.N., 639
Pham, T., 802
Phillips, M., 210, 374
Pohtilla, J.F., 317
Pope, M.H., 256, 278, 314, 518,
 521, 811, 840
Post, K.M., 219
Post, P.E., 770
Quintern, J., 608
Rabinowitz, W.M., 396
Raubenheimer, P., 729
Rebersek, S., 585, 627
Redford, J.B., 820
Reger, S.I., 289, 306, 336, 515, 533
Reich, N., 873
Reich, P., 84
Reinecke, S., 518, 521, 840
Richey, C.B., 765
Riley, P.O., 809, 835
Roberts, D., 544
Robinson, C.J., 331
Romich, B., 154
Rosen, J., 259, 627, 675
Rosen, M.J., 100, 151, 180, 829
Ross, D., 419, 547
Ross, J.D., 723
Ross, L.M., 240, 261
Rothschild, N., 91
Rovick, J.S., 814
Rowell, D., 299, 817
Rowley, B.A., 165
Roxborough, L., 573

Roy, S.H., 336
Roozendal, R.H., 483
Russell, D., 43
Ryan, S., 91
Sabelman, E.E., 371
Sacks, A.H., 302
Saito, Y., 202
Sasso, A.V., 290
Scadden, L.A., 388, 750
Schaad, G.M., 227
Scheffelin, M.M., 222
Schmidt, R.A., 583
Schneider, A.M., 287
Schnur, D.S., 814
Schoenberg, A., 633, 685
Schrager, R.J., 267
Schubert, R.W., 109, 385, 731
Schumann, T.L., 383
Schurman, D.J., 838
Scudder, G., 243
Schwander, T., 413
Schweitzer, J.R., 74, 76, 385
Seeger, B.R., 350
Segner, S.E., 550
Seroussi, R., 314, 811, 840
Servedio, A., 594
Servedio, F.J., 591, 594
Shaw, G., 87, 348, 480, 527
Shields, R.K., 530
Sherban, M., 235
Sheth, P.N., 486
Shimasaki, K.W., 210
Shipp, M., 65, 71, 81
Shire, B., 541, 683
Short, D.S., 3
Shuck, P.Y., 320
Siebens, A.A., 145
Sim, J., 697
Simic, V., 621
Simon, E., 600
Simon, H.J., 401
Singleton, D., 213
Sirett, R.J., 883
Smith, G.A., 462
Smith, R.O., 341
Smits, J.J., 781
Snell, E., 539, 683, 717
Snowball, H., 474
Soede, M., 115, 133, 805
Somerville, N., 37
Spaeth, D.M., 136
Stanfill, L., 544
Stanic, U., 621
Steege, J.W., 814
Steele, R., 94, 157, 162, 431, 443, 451, 459
Stefanovska, A., 565
Stein, A., 256, 278
Stephanides, M.C., 675
Steven, P.M., 686
Stewart, T., 533
Stoker, R.G., 446
Stout, C.W., 559
Strojnik, P., 621
Strysik, J., 492
Stull, V., 594
Sullivan, J., 407
Suryaprased, A.G., 591
Swiffin, A.L., 124
Symons, J., 651
Takacs, H., 462
Taylor, S.J., 571
Tello, R.J., 299, 817
Tessaglia, D.L., 21, 296
Thierry, P.J., 805
Thrope, G.B., 660
Tobias, J., 2
Toraskar, J., 410
Tredwell, S., 573
Trefler, E., 510
Trencher, E.A., 848
Treviranus, J., 130
Turk, R., 565, 645
Ulrich, P.L., 60
Unruh, T.D., 380
Urbanovsky, J., 740
Valencic, V., 627
Van Balkom, H.L.M., 115, 133
Vanderheiden, G.C., 711, 750
Van der Loos, M., 796
Van Vorhis, R.L., 492, 814
Van Wagoner, E., 293
Van Woerden, J.A., 781
Veeger, H.E.J., 483
Vera, M., 168
Verburg, G., 466, 471, 697
Verplank, W., 459
Vervena, L.P., 336
Voda, J.A., 139
Vodovnik, L., 565
Waldron, M., 440
Walker, P.S., 267
Waltzman, S., 428
Warren, C.G., 9
Waters, R.L., 657
Weinrich, M., 94, 157, 162
Weisman, G., 2, 518, 521, 840
Weiss, M., 413
Welter, R.J., 576
Wengert, M.E., 216
Whalen, R.T., 821
Whitlock, J.A., 848
Whittle, M.L., 820
Whitworth, D.P., 864
Wilder, D.G., 811
Wilder, P., 314, 518
Wiley, M., 210
Williams, R.D., 504
Williams, III, T.W., 187
Williamson, T., 608
Willkomm, T.M., 767
Wilson, B.A., 642
Wise, S.A., 259
Woerpel, D., 745
Wong, Y., 259
Wood, R.C., 838
Woodall, H.E., 37
Woude, L.H. van der, 483
Wright, K.C., 579
Wu, Y., 139, 608
Wurster, R.D., 331
Yamaguchi, G.T., 843
Yarkony, G., 608
Yazdani-Kachoee, B., 148
Yousef, N., 290
Yund, E.W., 401
Zajac, F.E., 581, 582, 636, 843
Zerkus, M., 87, 275
Zimmerman, S., 809
Zondlo, F.C., 281
Zurek, P.M., 395
Zysman, S., 576

MEETING THE CHALLENGE

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